LAKESHORE CAPACITY STUDY

INTEGRATION

A Simulation Model for Predicting the Impact of Lakeshore Cottages on the Environment

JULY 1986

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Trophic Status
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LAKESHORE CAPACITY STUDY

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LAKESHORE CAPACITY STUDY

Muskoka-Haliburton Area

0 5 10 15 20 25 30 35

Scale in kilometres

COMPONENTS:

- Wildlife
- Trophic Status
- All
- Microbiology
- Fisheries
- Land Use

The regional survey by the Land Use Component of cottages on portions of lakes is not included

Note: Circle sizes for Cartographic purposes only

Cartography by Ministry of Municipal Affairs and Housing, 1981

Eagle Lake
Bernard Lake
Island Lake
Pickerel Lake
Grass Lake
Jacks Lake
Loon Lake
Sand Lake
Three Mile Lake
Groom Lake
Peters Lake
Clam Lake
Doe Lake
Emsdale Lake
Clear Lake
Foote Lake
Dotty Lake
Oxbow Lake
Perch Lake
Walker Lake
Bella Lake
Oudaze Lake
Rebecca Lake
Little Clear Lake
Buck Lake
Jerry Lake
Solitaire Lake
Troutspawn Lake
Harp Lake
Lower Fletcher Lake
Bear Lake
Seventeen Mile Lake
McFadden Lake
Clinto Lake
Lake Vernon
Peninsula Lake
Fairy Lake
Tock Lake
Kewagama Lake
Johnson Lake
Macdonald Lake
North Lake
Lake of Bays
Mary Lake
Beattie Lake
Skeleton Lake
Mink Lake
Paint Lake
Percy Lake
Clearwater Lake
Menominee Lake
Chub Lake
Shoe Lake
Mouse Lake
Redstone Lake
Eagle Lake
Haliburton Lake
Grandview Lake
Martin Lake
Blue Chalk Lake
Plastic Lake
Big Hawk Lake
Konnisis Lake
Moose Lake
Fawn Lake
Big Stephen Lake
Echo Lake
Rii Lake
Black Lake
Kabakwa Lake
Little Hawk Lake
Maple Lake
Bonnie Lake
Moot Lake
Dickie Lake
Wildcat Lake
Red Chalk Lake
Halls Lake
Glen Lake
Bessaunt Lake
Sage Lake
Gullfeather Lake
Green Lake
Two Islands Lake
Crosson Lake
Pine Lake
Cinder Lake
Brady Lake
Hurricane Lake
Mishwabi Lake
Gilleach Lake
Healey Lake
Kushog Lake
Twelve Mile Lake
Esson Lake
Leonard Lake
Leech Lake
McKay Lake
Boshkung Lake
Mountain Lake
Kashagawigamog Lake
Wood Lake
Bigwind Lake
Bird Lake
Glamour Lake
Billings Lake
Silent Lake
Minden
Little Bob Lake
Gull Lake
Sludge Lake
Davis Lake
Head Lake
Four Mile Lake
Dalrymple Lake
Lake Couchiching
Mississagua Lake
Lower Buckhorn Lake
Lovesick Lake
Three Mile Lake
Kahshe Lake
Gravenhurst
Muskoka Bay
Bracebridge
Huntsville
Parry Sound
Stewart Lake
Lake St. Peter
Bancroft
Haliburton
Minden
THE DISTRICT MUNICIPALITY OF MUSKOKA
THE DISTRICT OF PARRY SOUND
THE DISTRICT OF NIPISSING
THE PROVISIONAL COUNTY OF HALIBURTON
THE COUNTY OF HASTINGS
THE COUNTY OF PETERBOROUGH
THE COUNTY OF VICTORIA
THE COUNTY OF SIMCOE
Muskoka R.
Gull River
Irondale River
Black River
Severn River
Burnt River

FOREWORD

Community planners and other professionals involved in the preparation of planning policies for lakeshore development and in the review of specific subdivision proposals have always found it difficult to determine objectively the impact of development on the natural environment. In response to this challenge, the Lakeshore Capacity Study was undertaken to provide a planning tool to assist in evaluating the effects of cottage development on inland lakes and lakeshores. Central to the task was the need to gain a clearer understanding of the relationship between cottage development and its impacts on selected aspects of the natural environment.

To accomplish these objectives, the Ministry of Municipal Affairs carried out the Lakeshore Capacity Study in co-operation with the Ministry of the Environment and the Ministry of Natural Resources.

The Muskoka-Haliburton area of central Ontario was chosen as the Study Area. The homogeneity of the area, which is part of one physiographic region, reduced the need to account for major natural variations among the lakes and watersheds. In addition, the extent of existing development on the lakes varied, permitting an examination of situations ranging from no development to full development.

The Study involved measuring the source of environmental impact, in terms of the lakeshore cottages and their use, and the impact of cottage development in terms of water quality, fisheries, and wildlife habitat. The methods of prediction derived from the research were linked in a simulation model, which is capable of predicting trends in the values of the key indicators of impact.

As the research, analysis and findings of the Study are documented in a set of seven reports, selective reading may be desirable. Those readers who have a general interest in the work are advised to read the Committee Report first, as it provides an overall summary of the findings. This should be followed by the Integration report, in which the simulation model is described. Readers with more specialized interests will find the details of each component of the Study in the other five reports. In each report, the reader can select from the table of contents the most important chapters for his or her purposes.

The end product of the Study, the Ontario Lakeshore Capacity Simulation Model, has several features worth noting. The spatial unit addressed by the model is a single lake and the lakeshore. When the model is applied, the number of unknowns related to the natural environment can be substantially reduced, making it easier for planners or other professionals to weigh the environmental effects of development. The model goes a step further to permit predictions of the impact of cottage development when different management policies are selected.

The scope of the simulation model demands some explanation In its present form, the model applies to cottage development on inland lakes in the Study Area, where the research was conducted. However, the methods of prediction can be adapted to other parts of the province, as long as differences in conditions are taken into account.

The purpose of the Study was to measure the environmental impact of cottages. Commercial and industrial uses were excluded deliberately, in order to simplify the difficult task of measuring cottage impact. The flexibility inherent in the simulation model makes it possible to add other types of land use later, if so desired.

Most of the existing cottage development in the Study Area is located in a single tier along the shoreline. For this reason, the simulation model applies to the immediate lakeshore and not to backshore development. Again, the methods of prediction developed for cottages near the lake can be adapted to measure the impact of cottage development in other forms.

The model was designed to measure the physical and chemical impacts of cottages. Accordingly, it does not address other planning concerns, such as social and economic impacts. While these were recognized as essential considerations in decision-making, the specific objective of Phase III of the Lakeshore Capacity Study was to find practical ways of producing better technical data regarding environmental impact.

Now that Phase III of the Study is completed, with the production of the Ontario Lakeshore Capacity Simulation Model (OLCSM), the next step envisaged is to apply the model experimentally within the Ministry. In this setting, model output can be tested in a variety of actual development situations. When this period of experimental use has been concluded and the results assessed, the three participating ministries will be able to determine whether the model should be adapted to other parts of the province and whether it should be made available more widely.

The Ministry of Municipal Affairs considers the OLCSM to be a potential planning tool but recognizes that the technical and organizational implications of its use must be examined. While this is underway, the model will be available for testing as an additional planning tool to supplement the information normally required to evaluate a planning policy or development proposal. However, the model will not be used in the decision-making process, which will still rest on the customary range of planning considerations.

This Integration report describes the Ontario Lakeshore Capacity Simulation Model (OLCSM) developed in Phase III of the Lakeshore Capacity Study.

ACKNOWLEDGEMENTS

Without the participation and support of the Lakeshore Capacity Study component managers and staff, the simulation model would not have been possible. For their many contributions in terms of original component research results and ideas, we thank C. Allan Burger, Microbiology; Peter J. Dillon, Trophic Status; Jean C. Downing, Land Use; David L. Euler, Wildlife; and Allen M. McCombie, Fisheries.

The fundamental structure of the simulation model was developed at two workshops, attended by over forty participants from three ministries. This model is, at least in part, the result of their creative efforts.

Finally, the assistance of ESSA Ltd. in the use of the Adaptive Environmental Assessment and Management approach, gave clear direction to the modelling process. We thank ESSA's Robert R. Everitt, Peter MacNamee, David R. Marmorek, Nicholas C. Sonntag and Michael J. Staley for designing and coding the initial model, and Pille Bunnell for preparing a comprehensive set of graphics to illustrate the model's development, internal structure and output.

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1. SUMMARY

The Ontario Lakeshore Capacity Simulation Model (OLCSM) was developed as part of the Lakeshore Capacity Study to assist in planning for cottage development on the shores of inland lakes in Ontario. With the model, it is possible to predict changes through time that are likely to occur in the land/lake environment, with respect to water quality, fisheries and wildlife, in response to shoreland cottage development.

The inner workings of the model are mathematical relationships, based on the current understanding of lake-watershed ecosystems. The model output, in the form of projections of selected environmental indicators, provides information on the development capacity of the lake under consideration.

In addition, different management scenarios can be simulated to determine the environmental consequences under each set of conditions. The various management options can then be weighed, based on tangible measures of environmental impact. With this type of analysis, several acceptable levels of cottage development may be predicted, depending on the management strategy selected.

1.1 THE APPROACH

The Adaptive Environmental Assessment and Management methodology, used to construct the model, prescribes a coordinated interdisciplinary approach that takes into account the needs and concerns of the ultimate users. Inherent in the process are short, intensive, modelling workshops which, for the Lakeshore Capacity Study, included scientists, planners, resource managers and policy advisors from the three participating ministries.

The OLCSM incorporates (a) the predictive models developed by researchers in the various components of the Lakeshore Capacity Study, (b) relevant data from the scientific literature, and (c) an intuitive understanding of the lake-watershed system. The present version of the model applies to the Muskoka-Haliburton area of central Ontario, where the research was conducted.

1.2 THE SUBMODELS

The OLCSM is divided into four subsystems, or submodels: Land Use, the source of the impact; and Water Quality, Fisheries and Wildlife-Habitat, the submodels that calculate the environmental impact. Cottage use, identified as the major source of environmental impact from lakeshore development, is predicted in the Land Use Submodel. Output from this submodel is used in the Water Quality, Fisheries and Wildlife-Habitat submodels.

The Water Quality Submodel has two parts: one predicts the lake nutrient level, or trophic status, plus related water quality indicators, such as oxygen levels and transparency; the other is concerned with the health-related microbiology of lake water.

The Fisheries Submodel calculates the amount of fishing pressure, harvest and fish stock in a lake, in response to changes in the number of cottages, cottage use and the number of anglers. The two sport fish species selected for inclusion in the model are lake trout and smallmouth bass. The submodel is designed so that the lake trout are affected by reduced oxygen concentrations in the lake, whereas the smallmouth bass population changes in response to habitat alterations in the littoral zone.

In the Wildlife-Habitat Submodel, the impact of cottage development on wildlife is calculated indirectly from changes in the shoreland vegetation. This "habitat approach" emphasizes wildlife habitat disturbance. The wildlife included in the model are small mammals, songbirds, mink, loons, hawks, deer and turtles.

The linkages between the submodels represent only the key interactions necessary for the prediction of impact.

1.3 INPUT, OUTPUT AND OPERATION

The submodel equations are designed to use data that are readily available. The input data necessary to run the model can be assembled largely from existing data bases. The input consists of lake-specific data, such as the lake morphometry, the lakeshore forest and littoral zone types around the lake, and the location of existing cottages, existing vacant lots and proposed cottage lots.

The output consists of values for a set of indicator variables which function as gauges, or measures, of the response of the system. These values are plotted as graphs, or printed in tabular form, for a user-specified interval of time and length of simulation. When alternative management strategies are simulated, the indicator values may be compared.

The management strategies correspond to the controls which can be exercised as part of a policy. The strategies can be introduced or terminated at any time during the simulation.

1.4 FUTURE REFINEMENTS

The OLCSM is not intended to be immutable. The present version is capable of predicting the environmental impact of lakeshore cottage development and testing the effects of various mitigative measures. The next version should incorporate some or all of the refinements cited in the report as desirable to improve the model's predictive capability. The model should then be tested in extreme situations, to ensure that it is responsive to the full range of conditions in the Study Area. Subsequent versions of

the OLCSM should reflect advances in the scientific understanding of lake ecosystems.

2. LAKESHORE CAPACITY STUDY CHRONOLOGY

2.1 PROBLEM DEFINITION

The objective of the Lakeshore Capacity Study (LCS) was to develop a comprehensive management and planning tool for assessing the impact of cottage development on inland lakes in Ontario. This approach was based on the premise that the preferred course in the management of a renewable resource is to avoid deterioration of the resource rather than to apply corrective measures after problems arise. The government recognized the need for a scientifically-based, systematic approach to the prediction of the impact of cottage development that would aid in the evaluation of proposed plans of subdivision, the preparation of official plans and the formulation of lake development policies.

2.2 RESEARCH PHASES — FORMATION OF LCS STRUCTURE

Phase I of the LCS was a feasibility study conducted by the Institute of Environmental Sciences and Engineering, University of Toronto (University of Toronto 1971). It consisted of a survey of literature outlining some of the major approaches to ecosystem modelling and a proposal for developing methods of measuring the impact of cottages on inland lakes in Ontario.

Phase II (University of Toronto 1974) included an elaboration of the recommended approach to the problem; the identification of ecological subsystems and subsystem elements that were important as indicators of the state of the system; an investigation of the adequacy of existing technical data for use in a predictive model; and an evaluation of the suitability of various physiographic regions in Ontario for field work. The Muskoka-Haliburton area was recommended as the most suitable location for conducting the research program (Figure 2.1). This area was selected as the lakes had similar geomorphological characteristics and a relatively uniform climate, thereby minimizing variation in the environmental parameters. In addition, lakes in the region had different levels of cottage development and environmental impact which was essential in order to establish a range of environ-

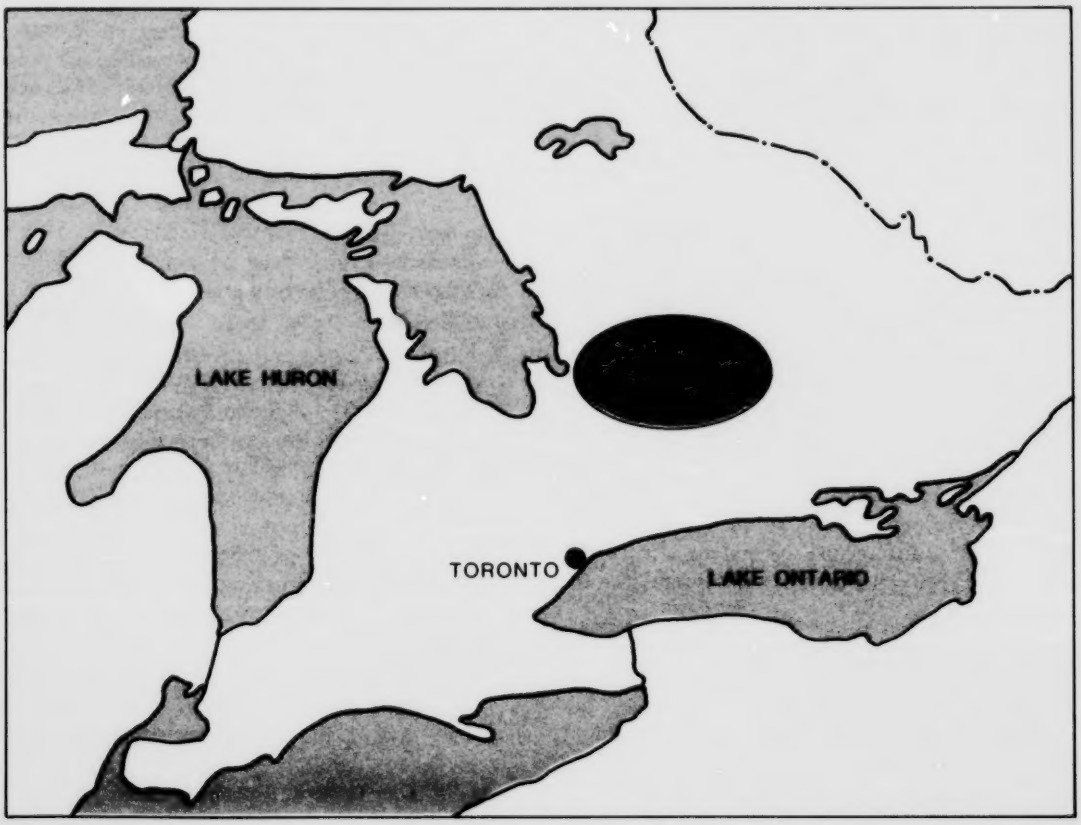


Figure 2.1 Location of Study Area

mental responses.

As outlined in Phase II, the system designated for study was the lake and its surrounding watershed. Two sets of variables were imposed on the system. The first was a set of natural forces such as solar radiation, precipitation, and wind, acting continuously on the system. The second was a set of anthropogenic (i.e. human-induced) forces, including cottaging, boating, swimming and angling, acting on the lake-watershed system at variable rates over a period of time.

The Phase III in-depth investigations were conducted by the Ontario ministries of Municipal Affairs and Housing, the Environment and Natural Resources. An interdisciplinary team of researchers from the three ministries was formed to develop predictive models with respect to cottage development and the direction and magnitude of environmental changes resulting from this type of development.

In the LCS Phase III, five research components were identified: Land Use, Trophic Status, Microbiology, Fisheries and Wildlife. Each represented a distinct part of the lake-watershed system and each involved research activities requiring specific technical knowledge. Within each component, important elements were chosen as indicators of the state of the subsystem.

The researchers conducted their investigations within the framework of the component structure. Because there was little existing research directly applicable to the Study objectives and substantial gaps in the scientific understanding of the resilience of the lake ecosystem to the impacts of development, the LCS investigators had to devise new approaches and research methods. The field data were used to generate quantitative relationships between development and the affected environmental parameters. For each component, a practical requirement was that the predictive capability be achieved principally with existing data, thus reducing the time expended in the review process.

It was anticipated that these research findings would then form the backbone of an integrated predictive model, capable of providing sound technical data to assist in the evaluation of proposed plans of subdivision and the preparation of official plans. The model was also expected to contribute to resource planning and management.

The impact of lakeshore cottages on the natural environment was the focus in Phase III. Human behaviour, attitudes, perceptions and socio-economic indicators were not explored. However, some aspects of the behavioural response to socio-economic factors were implicit in the methods of calculating cottage use and fishing effort and to that extent they were represented in the investigation.

2.3 LCS SUBSYSTEMS AND INDICATORS

The LCS components conducted research to derive methods of measuring and subsequently predicting the environmental changes likely to result from lakeshore cottage development.

The Land Use Component team investigated the source of the impact, which involved the cottages and cottagers, the extent and seasonal pattern of cottage use, and selected recreational activities in which cottagers participate. The relevant indicators for predictive purposes were the "cottage-day", one cottage in use for one day; and the "user-day", one cottage in use for one day by one person. Each can be expressed as a monthly, seasonal or annual value for all the lakeshore cottages on a given lake.

The Trophic Status Component group investigated the linkage between the man-made nutrient additions to a lake and its water quality. Lake phosphorus concentrations were used as the prime indicator of nutrient enrichment, as phosphorus is the nutrient most frequently controlling algae and aquatic plant growth in north temperate lakes. Other water quality indicators that are a function of ambient phosphorus levels are chlorophyll *a* concentration, algal biomass, water transparency and oxygen depletion in the hypolimnion.

The Microbiology Component specialists examined the effect of development on the occurrence and proliferation of a bacterium that causes *otitis externa*, the human disease known as "swimmer's ear". The prime indicator of swimming water quality in this study was the presence of the causal bacterium *Pseudomonas aeruginosa* in samples of lake water.

The Fisheries Component, which was divided into Net Productivity and Littoral Zone studies, was concerned with the impact of cottage development on the sport fish population in a lake. The Net Productivity scientists investigated the effect of angling pressure on the fishery and the relationship between angling effort, harvest and potential fish yield. An estimate of the maximum sustained yield for sport fish, based on lake morphometry and chemical factors, was used as the primary indicator of potential fish productivity in a lake. The cottager and non-cottager angling effort represented the pressure being placed on the fishery, whereas the fish harvest and biomass (stock) indicated the health of the sport fishery. Although data on all fish species were collected, the native lake trout *Salvelinus namayacush* was chosen as an indicator of the cold water fishery. This was done because they were found in many of the Study Area lakes, there was an angler preference for lake trout and they exhibited an extreme vulnerability to accelerated lake nutrient enrichment.

The Littoral Zone group investigated the effect of alterations in the nearshore habitat as a result of cottage development. The indicators were selected to give quantitative measures of the significance of habitat loss during key fish life-stages (Harker 1983). These indicators were: density of nests as a spawning indicator; density of young fish as a nursery indicator; and the densities of mature fish and prey organisms as indicators of the ability of the littoral zone to support fish in their feeding and resting areas.

The Wildlife Component scientists examined habitat modification associated with lakeshore cottages and the significance of these changes for representative animal species. Among the wildlife studied were songbirds, loons, hawks, small mammals, mink, deer, reptiles and amphibians. The species chosen occupy a wide range of ecological niches and therefore as a group are sensitive to the many direct and indirect impacts generated by development. The criteria for species selection in the Wildlife

Component were that they were (a) representative of major components of the wildlife community; and/or (b) valued highly by the public (for diverse reasons); and (c) present in sufficient numbers for study.

Several indices were used to gauge the extent of the impact on wildlife. The Area Development Index was used to predict the amount of vegetation disturbance and subsequent loss or gain of wildlife habitat (depending on the habitat preference of each species). Two indices of mink activity were also developed by the Wildlife Component. The Coefficient of Community was used as a measure of the extent of change in the native songbird species composition.

2.4 INTEGRATION PROCESS

The need to integrate the research findings into one predictive model which could be used to assist planners and resource managers was recognized from the outset of the Study. An exploratory literature review (Whitney et al 1978) was commissioned by the LCS Steering Committee to examine current approaches to environmental impact assessment modelling. From the group of relevant methodologies, the review identified those that were, in whole or in part, suitable to the objectives and design of the LCS and the integration process.

2.4.1 APPROACH TO INTEGRATION

The objective of the LCS was the development of a quantitative model, because of its usefulness in planning for lakeshore development. The research work had been done with this in mind and functional relationships had already been derived by the LCS components. Therefore qualitative models commonly used in environmental impact assessment were rejected.

The concept of a single carrying capacity for each lake was considered too rigid for the purposes of the study. This approach would preclude the consideration of potential variations in lake carrying capacity achieved through management strategies, such as modifications in subdivision design, restrictions on recreational activities (e.g. fishing) and reductions in nutrient loadings resulting from different types of sewage disposal.

A before-and-after approach was used by the LCS component researchers. However, for the purpose of integration, it was decided that temporal dynamics and interactions within the system over time should be explicitly included, to provide a more realistic simulation of actual conditions. For example, knowledge of the intermediate conditions on a lake would make it easier to explore the consequences of phased development. Also, if environmental impacts during the development period could be predicted at the outset, there would be sufficient lead-time to introduce suitable mitigative measures.

2.4.2 ADAPTIVE ENVIRONMENTAL ASSESSMENT AND MANAGEMENT

In their literature review, Whitney et al (1978) suggested that the most appropriate method of integrating the LCS component research was the approach (or at least some portion of it) developed by C.S. Holling and his colleagues at the Institute of Resource Ecology, University of British Columbia (Holling 1978). Whitney et al (1978) went on to describe several modifications to the approach which they considered more appropriate for the LCS. The concept of carrying capacity was recommended as the desirable framework for the integrated model.

After considering these proposals, the Integration Component researchers and the Study Steering Committee decided to adopt the Adaptive Environmental Assessment and Management (AEAM) modelling procedure to integrate the predictive methods developed by the components into a practical planning tool.

The AEAM approach prescribes the construction of a dynamic, computerized, simulation model, which explicitly accounts for the interactions (linkages) between compartments of the system under study. The complexity inherent in natural systems is minimized and the system is made more understandable by the use of simple yet robust mathematical relationships to describe the linkages in the model.

A simulation model is an abstraction of a real system, constructed to predict specific system responses. The projections indicate trends rather than exact solutions. This is useful in land use planning and resource management where an essential requirement of the model is to assist in environmental decision-making. The ease with which AEAM can be applied to the evaluation of resource management alternatives makes it helpful in resolving conflicts between opposing interests.

A critical ingredient of the AEAM approach is a series of intensive workshops during which a preliminary model is constructed and subsequently refined. The workshop participants (Appendix A) include scientists, planners, managers and policy advisors, from various disciplines (Figure 2.2). The composition of this group is designed to ensure that the model will reflect the needs and concerns of the potential users. The workshop dialogue encourages communication among those from different disciplines, which is valuable in defining their perspectives on lake planning.

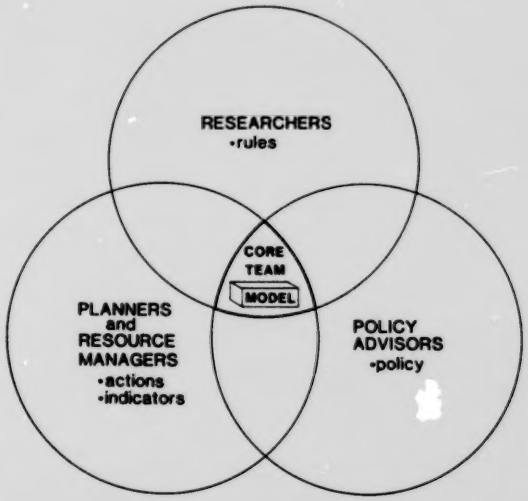


Figure 2.2 Workshop participants

3. ONTARIO LAKESHORE CAPACITY SIMULATION MODEL

3.1 MODEL STRUCTURE

The Ontario Lakeshore Capacity Simulation Model (OLCSM) is a type of simulation model sometimes referred to as a "state-transition discrete-time" model because the state of the system is described by variables that are changed at specified intervals of time. All natural events, such as precipitation, lake discharge and growth of the fish population, are implemented from the start of the simulation. The model contains a stochastic element in that random variation is applied to the annual nutrient loadings from precipitation and drainage, within the range observed in field studies.

Existing cottages are "built" at the start of the simulation. At any time thereafter, in response to a user-specified construction rate, cottages are built along the lakeshore on existing vacant lots and on lots in the proposed subdivision.

The parts of the OLCSM are illustrated in Figure 3.1. The inner workings of the model that provide the system dynamics, termed the "rules for change", describe in mathematical terms those processes and linkages between variables that are necessary for the prediction of impact on the environment. The rules are primarily a product of functional relationships derived by the LCS components from their research, supplemented with relevant data from the scientific literature and an intuitive understanding of the lake-watershed system. The levers represent the management strategies or "actions" that can be tested with the model. The dials depict the measures of the state of the system, or "indicators", which, when listed or plotted over time, comprise the model output.

The model is written in FORTRAN IV computer language and is run under the "operating system" called MTS (Michigan Terminal System), a general purpose time-sharing computer system. Access to the model is accomplished with a computer terminal link-up to the computer system.

The OLCSM is controlled by a computer program, Simulation Control System (SIMCON) which handles model input, output and record-keeping. SIMCON was designed for use with models that mimic changes over time.

The process of "running" the model involves a series of iterations (Figure 3.2). At each iteration the complete set of model equations is calculated, transforming the system state at time "t" to the system state at time "t + 1". The succeeding iterations are accomplished similarly. However, in each case, the system at time "t + 1" of the previous iteration becomes the new system at time "t".

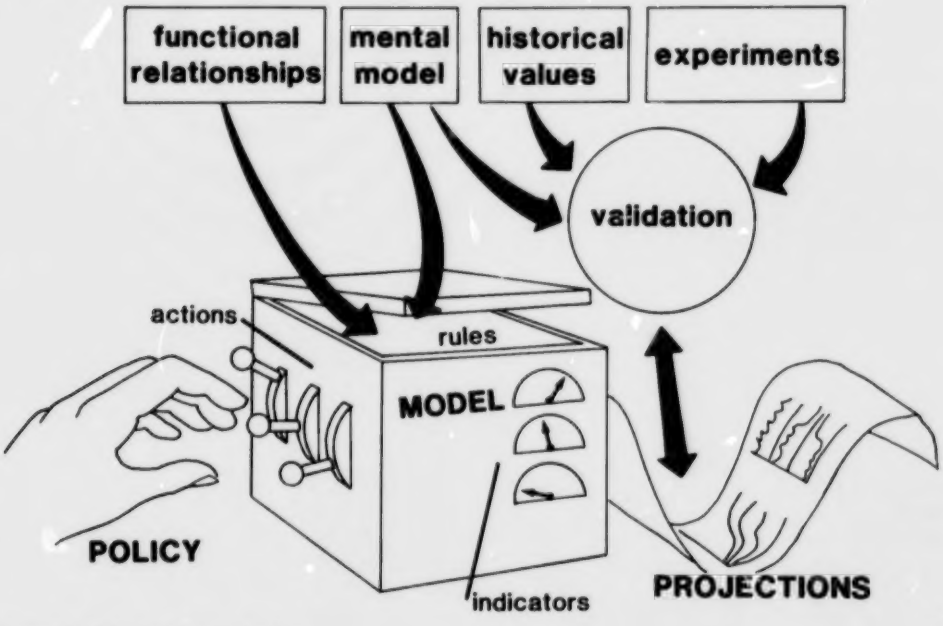


Figure 3.1 Modelling terminology

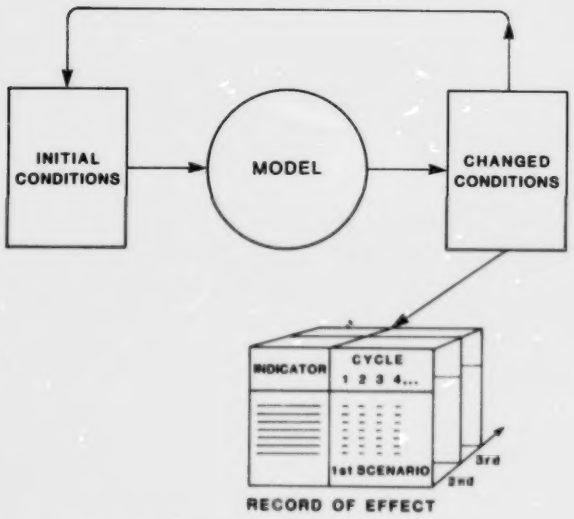


Figure 3.2 Model iteration and record-keeping for one cycle

SIMCON includes an intricate record-keeping system for retaining the values of each variable at each time-step, permitting the user to record changes in any variable during the time period of the simulation.

The model contains four subsystems, or submodels: Land Use, Water Quality, Fisheries and Wildlife-Habitat. Division of the system into subsystems facilitates examination of model coding and assumptions.

The structure of the submodels is prescribed by the format requirements of SIMCON. Each submodel is composed of four types of files: SOURCE, OBJECT, SET and COMMON (Figure 3.3). The user does not have direct access to the OBJECT file, as it is a machine-language translation of the SOURCE file. The SOURCE file contains the equations and other instructions which describe the system and indicate how the variables change over time. Variables and parameters are assigned values in the SET file. The COMMON file lists all the variables, along with the space in memory required for their storage. Initially, SET data are passed to the COMMON files. Each iteration uses these data, transforms values and retains the new and old values in the COMMON files.

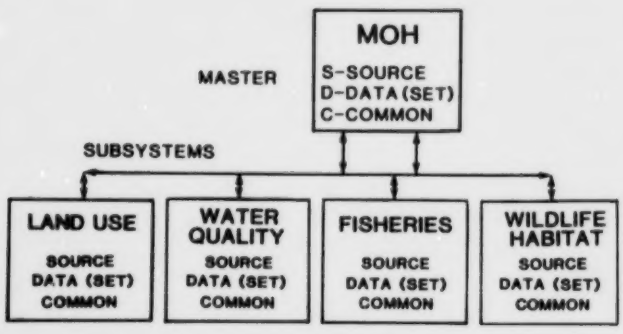


Figure 3.3 Ontario Lakeshore Capacity Simulation Model structure

A set of master files (MOH.S, MOH.D and MOH.C) links the submodels, allowing subsystem interactions and the sequencing of calculations between submodels. The master SET file contains, in addition to all the submodel SET files, the input data describing the specific lake characteristics that must be supplied to the model in order to evaluate conditions on a particular lake. The package of input data for each lake, describing the distribution of lots, forest cover, lake morphometry and other conditions specific to the lake, is termed a MACRO and is given a name, usually the name of the lake under study. By calling the MACRO, the user can obtain all the initial conditions for a specific lake.

The model output consists of numerical values for the environmental indicators (such as lake nutrient levels, fish stock or songbird habitat) that measure system behaviour. The values for these variables are calculated at each time-step for the duration of the simulation.

The model is designed as a practical tool with which to obtain, in the shortest possible time, the best information possible on the present and future state of the natural environment, as a basis for decision making. It provides an objective assessment of the changes that are likely to occur as a result of a set of conditions on a particular lake.

The responsible provincial and municipal agencies define the amount or percent of change in the lake environment that is acceptable. The priorities given to the indicators and the critical limits for the indicator values are drawn from these policies. A range of values may be used as guidelines, depending on resource plans and management policy.

3.1.1 SPATIAL AND TEMPORAL BOUNDARIES

3.1.1.1 SPACE

The submodels were developed principally from research in the Muskoka-Haliburton area of central Ontario. Therefore, the present version of the simulation model is valid only for this area.

The explicit spatial unit agreed on for the OLCSM is a single lake, surrounded by a 50-m band of shoreland. The band is broad enough to include single-tier lakeshore cottage development and the habitat for the selected wildlife-indicator species. To accommodate the songbird habitat, the lakeshore depth was extended to 100 m. Smaller spatial units were created for the Wildlife-Habitat Submodel by dividing the lakeshore and littoral zone into segments of uniform width for the collection of site-specific data on habitat types. These wildlife segments were also used to identify the location of cottage lots around the lake.

Nutrient loadings from upstream and the immediate watershed are explicitly included in the model. This is done to ensure that the level of development on upstream lakes, the types of land use within the watershed and the size of the watershed are considered in the calculation of the water quality indicator values (Figure 3.4). The model is structured so that chains of lakes can be evaluated. Beginning at the headwaters, the nutrient outflow from one lake is treated as nutrient input to the next lake downstream.

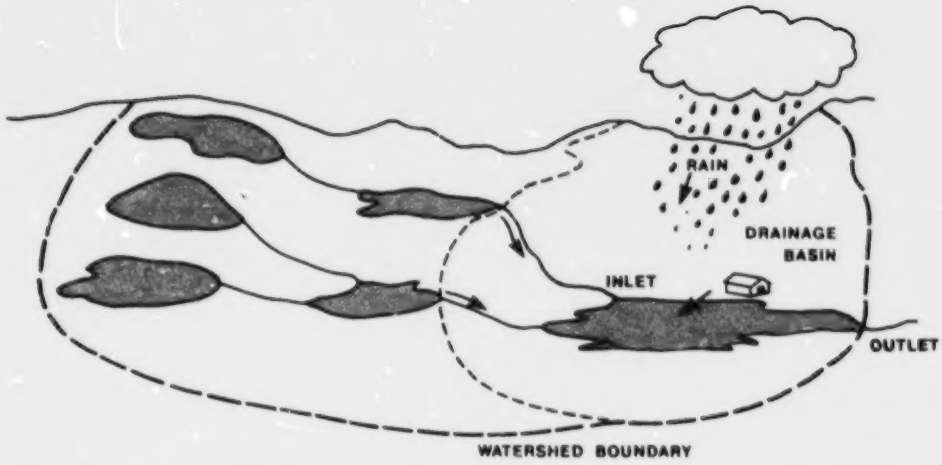


Figure 3.4 Spatial boundary: watershed including immediate drainage basin and upstream chains of lakes

3.1.1.2 TIME

The time step represents the increment of time between model calculations. In the present version, all submodels use an annual time-step, with the exception of the Water Quality Submodel (Figure 3.5). Within the annual time-step, monthly and seasonal events are calculated at the start of each year. In the Water Quality Submodel, the seasonal time-step is preferable because the phosphorus mass balance parameters can be more accurately estimated from seasonal data.

The length of each simulation (through time) is determined both by the needs of the user and the implications of the data. For predicting the impact of cottage development, a 20-year simulation is useful because it is an appropriate period for long-term planning. However, any time-period can be selected. To simulate the retention of sewage-derived phosphorus in the soil around the septic system, the length of time the soil retains its phosphorus-binding capacity must be carefully considered when setting a time horizon for the simulation. If the binding capacity of the soil continues beyond the simulation period, a reasonable prediction of the cottage impact on water quality would be impossible.

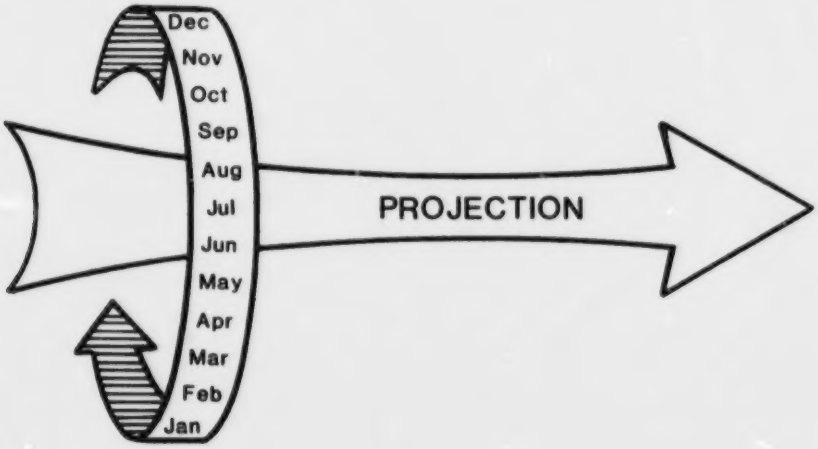


Figure 3.5 Time-step and length of simulation (e.g. 20-year projection)

3.1.2 INPUTS, ACTIONS AND INDICATORS

Some of the OLCSM variables remain relatively constant within the Study Area, e.g. annual phosphorus production per person. For these, uniform initial values are used for all lakes. However, lakes have many distinctive features for which specific values must be provided. The collection and organization of input data is described in a user's guide (Teleki and Herskowitz 1983a) which includes a data input form and instructions for entering the data into the computer. Most of the required input is available from established data bases, with the possible exception of information for the Wildlife-Habitat Submodel. If new wildlife-habitat data must be collected in the field, the survey could require several days, depending on the size of the lake.

The input data fall into four categories:

I. Required data: Values for some variables must be collected and entered into the computer in order to run the model (e.g. lake surface area, lake depth).

II. Useful data: Although the model is capable of calculating estimated values for certain variables, including actual values as input will improve the precision of model predictions (e.g. spring phosphorus concentration).

III. Optional data: Some parameters set in the model are based on average values in Muskoka-Haliburton (e.g. oxygen level at spring and fall turnover). Where possible, lake-specific data should replace the average values.

IV. Management data: The values of many variables may be altered in order to evaluate the effects of different management options (e.g. fishing season lengths).

System behaviour is measured in terms of meaningful and perceptible attributes termed indicators. These indicators comprise the model output and provide a measure of environmental impact. Those which are most useful to the user appear in the short list of the principal indicators in Table 3.1. The indicator values may be viewed in tabular form or plotted on graphs to illustrate the changes that occur in the environment over the period of the simulation.

Table 3.1 Principal indicators

Number of lakeshore cottages
Total number of annual user-days for lake
Summer dissolved oxygen minimum
Winter dissolved oxygen minimum
Seasonal and mean ice-free lake P concentration
Algal biomass over ice-free months (wet weight)
Zooplankton biomass over ice-free months (dry weight)
Proportion of water samples with PsA bacteria
Maximum Sustained Yield (MSY) for smallmouth bass and lake trout
Fish carrying capacity of lake (by species)
Fish biomass (by species)
Fishing effort (by species and season)
Fish harvest (by species and season)
Population indices for small mammals and songbirds
Hawk and loon nesting habitat loss
Mink activity index and disturbance factor

Selected management strategies, termed actions, may be introduced to mitigate the environmental impact of development. These actions pertain only to the parts of the ecosystem that can be managed and to modifications of the proposed development. When introduced or terminated at any time during the simulation, the actions correspond to the controls a manager might exercise as part of a management policy. Actions can be taken on any aspect of the lake-watershed system, e.g. modifications to the proposed plan of subdivision, the type of cottage access, the method of sewage disposal, or the length of the summer or winter fishing season (Table 3.2).

Table 3.2 Management strategies included in simulation model

SUBDIVISION RELATED
Regulate cottage density: lot width restrictions and number of lots allocated to each subdivision
Require staged development for proposed subdivisions
Control type of access, e.g. water, road, type of road and road maintenance
Control size of common beach
Negotiate cottage construction rate, e.g. through subdivider's agreement
Discourage cottage conversion from seasonal to permanent use
Modify subdivision design to avoid interference with critical wildlife habitat, e.g. location of road, lot or beach
WATER QUALITY RELATED
Limit phosphorus concentration in lake
Specify sewage system type and location for cottages
Require reduction of phosphates in sewage
FISHERIES RELATED
Shorten summer and/or winter angling season
Limit summer and/or winter catch
Encourage anglers to fish for underutilized species
Control public boat access
WILDLIFE-HABITAT RELATED
Reserve critical areas for deer, mink, loon, hawk and herptile habitat
Encourage cottagers to retain vegetation on lakeshore lots
Vary acceptable change in wildlife habitat

The model is designed to indicate the future repercussions of selected options which will assist the user in choosing the appropriate course of action. When several management scenarios have been simulated, the indicators from different scenarios can be compared. Ineffective actions can be identified and removed, leaving the most effective actions as a pool of viable management options.

Table 3.3 Data generated by each submodel

	Units
LAND USE	
total cottage-days for fishing seasons	
total user-days by month and by type of sewage system	
maximum number of swimmers at beach	
WATER QUALITY	
algal biomass	$mg \cdot L^{-1}$
chlorophyll *a* concentration	$\mu g \cdot L^{-1}$
Secchi depth	m
total phosphorus concentration (TP)	$\mu g \cdot L^{-1}$
areal hypolimnetic oxygen deficit (AHOD)	$mg \cdot m^{-2} \cdot day^{-1}$
zooplankton biomass	$mg \cdot m^{-3}$ (dry wt.)
proportion of water samples with *P. aeruginosa*	
minimum dissolved oxygen concentration	$mg \cdot L^{-1}$
Nitrogen:Phosphorus ratio	
FISHERIES	
lake trout biomass	$kg \cdot ha^{-1} \cdot year^{-1}$
smallmouth bass biomass	$kg \cdot ha^{-1} \cdot year^{-1}$
summer and winter catch	$kg \cdot ha^{-1} \cdot year^{-1}$
maximum sustained yield (MSY)	$kg \cdot ha^{-1} \cdot year^{-1}$
spawning habitat	m^2
fishing effort	angler-hrs $\cdot ha^{-1} \cdot yr^{-1}$
fish carrying capacity (K)	$kg \cdot ha^{-1}$
morphoedaphic index (MEI)	
WILDLIFE-HABITAT	
small mammal habitat	m^2
loon and hawk nesting sites	
littoral zone habitat for fish spawning	m^2
mink activity and disturbance index	
area development index (ADI)	
songbird habitat and breeding pairs	
critical areas flagged for preservation	
number of cottages in each year	

3.1.3 SUBMODELS AND THEIR LINKAGES

The research results of the LCS components are incorporated into four submodels, each designed to simulate a coherent part of the lake-watershed system (Table 3.3). Lake nutrient status and lake microbiology, which were investigated by separate components, are combined in the OLCSM Water Quality Submodel.

The linkages between submodels are summarized in the submodel interaction matrix (Table 3.4). For each submodel, it includes the information that is considered essential in describing the other model subsystems. For example, the Land Use Submodel generates cottage-day and user-day data for all other submodels because these variables are a measure of cottage development, the source of the impact. The data on oxygen and lake phosphorus concentrations generated by the Water Quality Submodel and passed to the Fisheries Submodel reflect the linkages between water quality and fish biomass. The Wildlife-Habitat Submodel calculates changes in the amount of fish spawning habitat which is subsequently used in the Fisheries Submodel to modify the fish carrying capacity of the lake. Also the number of cottages constructed in the Wildlife-Habitat Submodel is passed to the Land Use Submodel, for the predictions of total cottage use on the lakeshore.

The interactions between the submodels are selective rather than exhaustive. They are restricted to those that predict the behaviour of indicators related to the impact of lakeshore cottage development on the lake and surrounding shoreland.

The internal operation of each submodel and the linkages between submodels are described in the following four chapters.

Table 3.4 Submodel interaction matrix

FROM \ TO	LAND USE	WATER QUALITY	FISHERIES	WILDLIFE-HABITAT
LAND USE	all variables internal to submodel	user-days/month by sewage system type distances from beaches to nearest septic system maximum beach swimmers on day of highest use in each summer month	cottage-days/ month in summer and winter fishing seasons public boat access (non-cottager anglers)	total user-days in month of maximum use (July)
WATER QUALITY		all variables internal to submodel	Total Dissolved Solids (TDS) phosphorus concentration minimum oxygen concentration in hypolimnion zooplankton biomass	
FISHERIES			all variables internal to submodel	
WILDLIFE-HABITAT	number of cottages in each year (total for lake and by subdivision)		number of cottages/ 1000 m of shoreline	all variables internal to submodel

4. LAND USE SUBMODEL

Research by the Land Use Component planners and social scientists was concentrated largely on cottage use (Downing 1986). The methods developed to predict annual cottage use reflected differences between cottages with regard to type of access (e.g. road or water) and pattern of use (e.g. seasonal or year-round).

The Land Use Submodel applies these methods to estimate the amount of use a cottage will receive annually. The number of annual user-days is allocated to months and to the type of sewage system associated with the cottage. This information is used in the Water Quality Submodel to predict the amount of phosphorus generated from lakeshore cottages. Cottage use information is also passed to the other submodels.

The computer code which handles cottage construction is in the Wildlife-Habitat Submodel, because it is necessary to identify the location of cottages with respect to the wildlife segments for estimating impact on the wildlife community. However, it is more appropriate to describe cottage construction here, in association with cottage use.

4.1 COTTAGES

The model is programmed to handle five different subdivisions or sections of lakeshore, each with its own construction rate, start-up time and types of sewage system. The existing development consists of both cottages and vacant (undeveloped) lots, as each lot represents one potential cottage. The proposed subdivisions in the model represent cottage subdivision applications (real or hypothetical). Following the placement of existing cottages along the lakeshore at the start of the simulation, cottages are constructed annually on existing vacant lots and proposed lots.

The Wildlife-Habitat Submodel requires a fixed grid system in order to relate the location of cottages to the types of wildlife habitat around the lake. Therefore, the 50-m deep band of shoreland is divided into segments of uniform width which may be 50-200 m in width depending on the length of the lakeshore. Consistency is maintained between the location of cottages recorded in both the Wildlife-Habitat (Chapter 7) and Land Use Submodels, by simulating the development of wildlife segments rather than lots.

The cottage construction rate for each subdivision represents the proportion of undeveloped segments to be developed each year. For example, a subdivision may occupy 20 segments. If the construction rate is 0.5 and the subdivision begins in the first year, 10 segments would be developed in year one, 5 in year two, and so on, until the subdivision is completed. The segments are developed in a sequence assigned by the user. When a segment is developed, cottages are constructed on all lots located within the segment (Figure 4.1).

The "lot" referred to in this report is that part of the registered lot within the 50-m band of shoreland. Therefore, the lot size in the model is the width (m) of the registered lot multiplied by 50 m. For a given plan of subdivision, the user must calculate the average lot size in each wildlife segment. Lot size is important because it is interpreted in the Wildlife-Habitat Submodel as a factor affecting the extent of wildlife habitat disturbance.

In order to simulate cottage development and to predict cottage use, the following data are required:

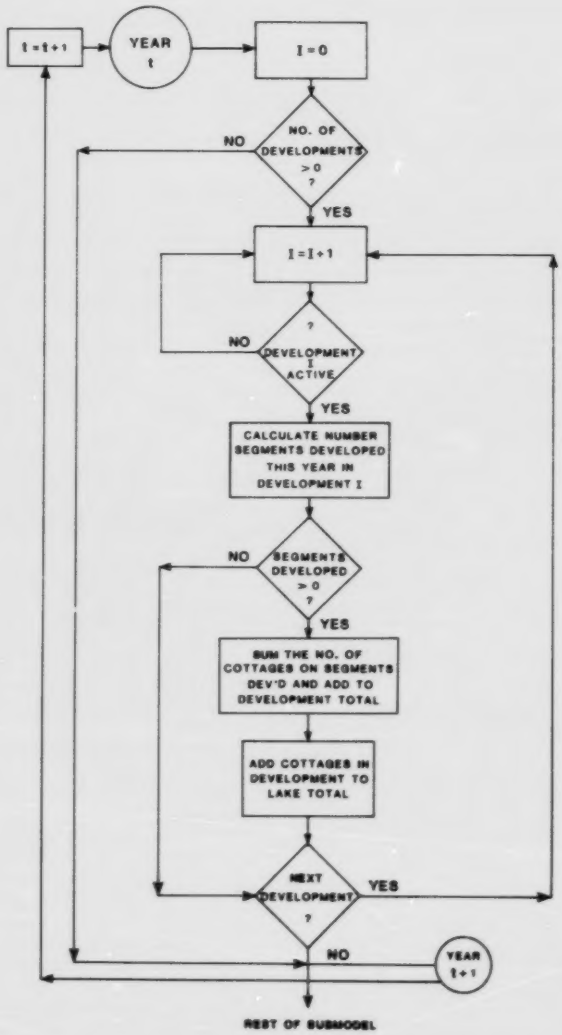


Figure 4.1 Flow chart of major events in the calculation of development ("development" refers to a subdivision or a section of lakeshore; I = development number)

A. To determine lot size and location of cottages:
   (a) number of existing and/or proposed lots in each wildlife segment,
   (b) average lot size for each wildlife segment with existing and/or proposed lots,
   (c) sequence of segment development,
   (d) rate of cottage construction, and
   (e) year construction is started in proposed subdivision.

B. To determine use of cottages:
   (a) type of access (road or water only),
   (b) summer and winter road access,
   (c) distance to nearest hard-surfaced road,
   (d) distance to nearest high order urban service centre, and
   (e) cottage typology (proportion of cottages in each of three cottage typology groups) from selected benchmark lake.

If special local conditions (Section 4.2.2) indicate that an increased (or decreased) rate of conversion from seasonal to permanent residences can be expected, the conversion rate is expressed as a decimal fraction plus 1 (e.g. 5% = 0.05 + 1 = 1.05).

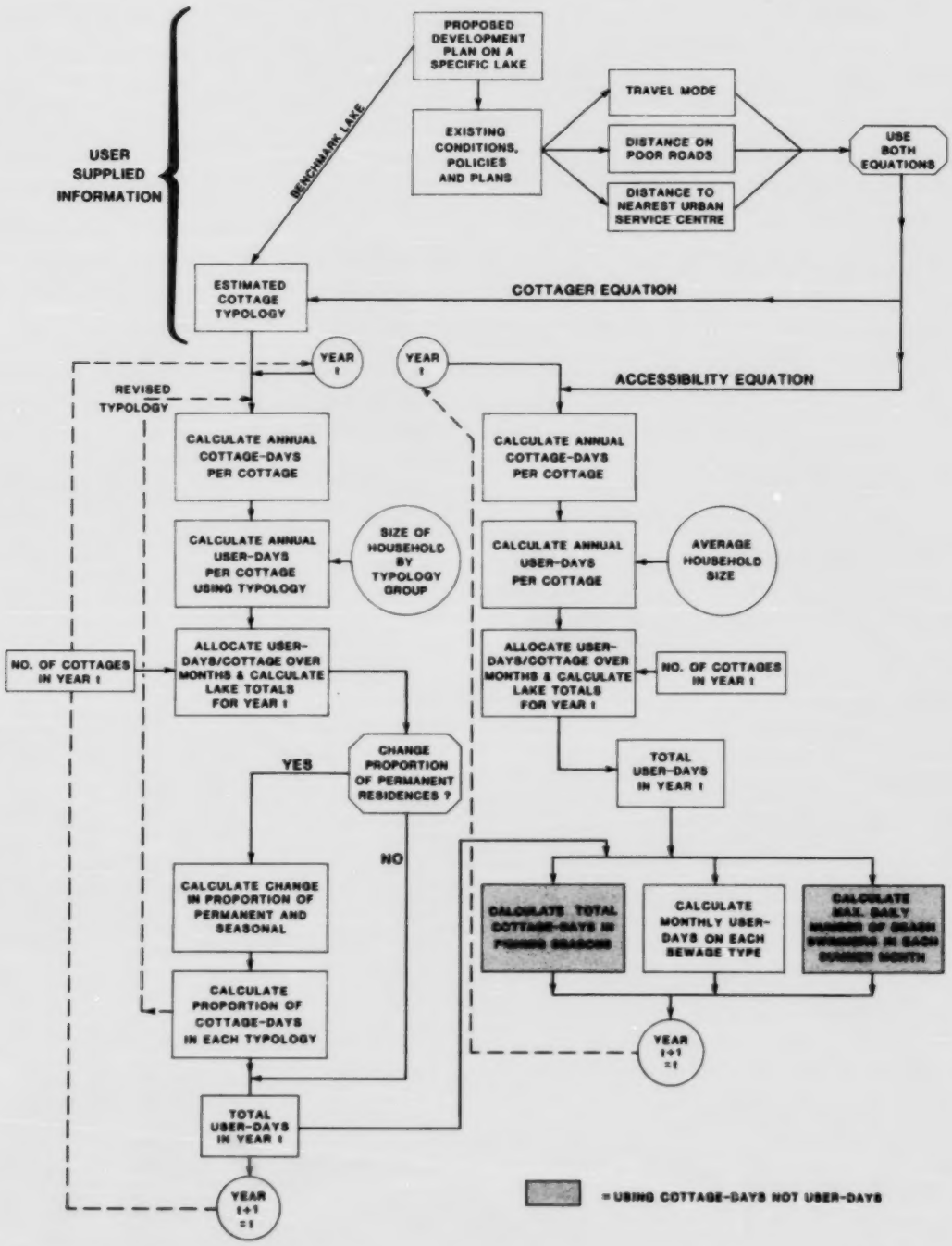

USER SUPPLIED INFORMATION
PROPOSED DEVELOPMENT PLAN ON A SPECIFIC LAKE
BENCHMARK LAKE
EXISTING CONDITIONS, POLICIES AND PLANS
TRAVEL MODE
DISTANCE ON POOR ROADS
DISTANCE TO NEAREST URBAN SERVICE CENTRE
USE BOTH EQUATIONS
ESTIMATED COTTAGE TYPOLOGY
COTTAGER EQUATION
ACCESSIBILITY EQUATION
YEAR i
YEAR i
REVISED TYPOLOGY
CALCULATE ANNUAL COTTAGE-DAYS PER COTTAGE
CALCULATE ANNUAL COTTAGE-DAYS PER COTTAGE
CALCULATE ANNUAL USER-DAYS PER COTTAGE USING TYPOLOGY
SIZE OF HOUSEHOLD BY TYPOLOGY GROUP
CALCULATE ANNUAL USER-DAYS PER COTTAGE
AVERAGE HOUSEHOLD SIZE
NO. OF COTTAGES IN YEAR i
ALLOCATE USER-DAYS/COTTAGE OVER MONTHS & CALCULATE LAKE TOTALS FOR YEAR i
ALLOCATE USER-DAYS/COTTAGE OVER MONTHS & CALCULATE LAKE TOTALS FOR YEAR i
NO. OF COTTAGES IN YEAR i
CHANGE PROPORTION OF PERMANENT RESIDENCES ?
YES
NO
TOTAL USER-DAYS IN YEAR i
CALCULATE CHANGE IN PROPORTION OF PERMANENT AND SEASONAL
CALCULATE TOTAL COTTAGE-DAYS IN FISHING SEASONS
CALCULATE MONTHLY USER-DAYS ON EACH SEWAGE TYPE
CALCULATE MAX. DAILY NUMBER OF BOATS SWIMMERS IN EACH SUMMER MONTH
CALCULATE PROPORTION OF COTTAGE-DAYS IN EACH TYPOLOGY
YEAR i+1 =i
TOTAL USER-DAYS IN YEAR i
YEAR i+1 =i
= USING COTTAGE-DAYS NOT USER-DAYS

Figure 4.2 Land Use Submodel flow chart

4.2 COTTAGE-DAYS AND USER-DAYS

The major indicators of the Land Use Submodel that are employed in the other submodels are: 1) the cottage-day, one cottage in use for one day, and 2) the user-day, one cottage in use for one day by one person. These are expressed as the annual sum for all lakeshore cottages around a given lake.

The cottage use indicators are calculated from two equations, the Accessibility and the Cottager equations, developed by the Land Use Component (Downing 1986) to predict cottage-days. The subsequent conversion to user-days takes into account average household size and, in the case of the Cottager equation, also the cottage typology. A flow chart for the calculation of the cottage use indicators appears in Figure 4.2.

The accessibility variables can refer to a subdivision, a portion of a subdivision, a section of lakeshore or the lakeshore as a whole. The choice depends on the lake size, uniformity of travel mode, whether more than one "nearest urban centre" is involved and whether the distance on poor roads varies widely. For convenience, the descriptions of the accessibility variables in this chapter refer to a subdivision.

4.2.1 ACCESSIBILITY EQUATION

The Accessibility equation reflects variations in cottage use, as a function of selected factors related to cottage accessibility. The Accessibility equation below predicts annual cottage-days per cottage (COTDA):

$$\begin{aligned} COTDA = {} & 83.105 + 93.452\,TMODE1 + \\ & 22.655\,TMODE2 + 21.972\,TMODE3 - \\ & 0.529\,DISTSUMH + 0.322 \\ & MAXPOORX \end{aligned} \qquad (4.1)$$

where TMODE1 = predominant travel mode to subdivision is car in summer and winter (0 = no, 1 = yes);

TMODE2 = predominant travel mode to subdivision is car in summer, other in winter (0 = no, 1 = yes);

TMODE3 = predominant travel mode to subdivision is boat in summer and other than car in winter (0 = no, 1 = yes);

DISTSUMH = mean distance from cottages in the subdivision to the nearest high order urban service centre (km); and

MAXPOORX = inverse of mean distance from cottages in the subdivision to the nearest paved road (km^{-1}).

Note: TMODE4 is the reference category in this regression equation. Only one of the TMODE variables can be equal to 1 for any given subdivision; the others equal 0.

The travel mode variable reflects higher use when the cottage is accessible by road and lower cottage use when it has water access only. Similarly, where the road is closed in winter, cottages are more difficult to reach and tend to be used less. The distance from the cottage to the nearest paved road also affects cottage use. The third variable relating to access is the distance to the nearest large urban service centre in the region. While short-stay cottagers, such as weekenders, have little or no need for local services, those who stay for longer periods need to replenish their supplies periodically. Year-round lakeshore residents need a wider range of services, including banks and medical facilities, and are more likely to locate closer to large urban centres in the region (Downing 1986).

To calculate the annual user-days for each cottage, the predicted number of cottage-days per cottage (Equation 4.1) is multiplied by the average household size of 3.067 people. Finally, the total number of user-days associated with the subdivision, in each simulated year, is the product of the annual user-days per cottage multiplied by the total number of cottages in the subdivision in that year. For the entire lakeshore, the totals for the various subdivisions are summed.

The Water Quality and Fisheries submodels require total user-days and cottage-days by month, respectively, for the entire lake. Using data from the Land Use Component, the average proportion of annual cottage use in each month is applied in the submodel to calculate the average monthly distribution of user-days and cottage-days.

4.2.2 COTTAGER EQUATION

The Cottager equation predicts cottage-days from the perspective of how the cottage is used. Three distinct patterns of cottage use were identified (Downing 1986) and the proportion of cottages in each of these three categories is termed the cottage typology. This can be thought of as a record of the end result of the diverse decisions made by cottagers concerning the use of their cottages. The decisions are based on a broad array of internal and external factors, such as socio-economic characteristics of the cottage household and cost of gasoline.

The three cottage typology groups are defined as follows:

Seasonal: Cottages used predominantly during the summer (July and August); on weekends in the spring, summer and fall; and on long weekends in the spring, summer and fall.

Extended Summer: Cottages with a high level of use (weekends and weekdays) throughout the spring, summer and fall.

Permanent Residents: Cottages used all year, as principal residences.

In order to predict cottage use for a proposed subdivision, the proportion of cottages in each typology group is estimated. This is accomplished by selecting an appropriate "benchmark" lake from the pool of 36 benchmark lakes, for which the cottage typology proportions are known. The benchmark lake's cottage typology is then applied to the total cottage-days for the proposed subdivision. The method of selecting the appropriate benchmark is based on matching the accessibility characteristics of the target lake or subdivision with those of a benchmark lake, assuming that differences in accessibility are associated with differences in cottage use. The benchmarking

process has been documented in detail in the Land Use Component Technical Report (Carroll et al 1983).

The Cottager equation below predicts annual cottage-days per cottage (COTDA):

$$\text{COTDA} = 68.312 + 278.578\,\text{PERMANENT} + 102.042\,\text{ESUMMER} + 21.291\,\text{TMODE1} + 12.623\,\text{TMODE2} - 0.191\,\text{DISTSUMH} \quad (4.2)$$

where PERMANENT = proportion of cottages in typology group Permanent Residents (as determined from benchmark lake);

ESUMMER = proportion of cottages in typology group Extended Summer (as determined from benchmark lake);

TMODE1 = predominant travel mode to subdivision is car in summer and winter (0 or 1);

TMODE2 = predominant travel mode to subdivision is car in summer, other in winter (0 or 1); and

DISTSUMH = mean distance from the cottages in the subdivision to the nearest high order urban service centre (km).

Note: The SEASONAL typology group is the reference category in this regression equation and is included as the constant 68.312.

The conversion of total annual cottage-days for the lakeshore to user-days, using the Cottager equation, proceeds as follows:

$$\text{total annual user-days} = \sum_{i=1}^{3} TCD_t \cdot P_t(i) \cdot HSIZE(i) \quad (4.3)$$

where Σ = summation

$\cdot$ = multiplication symbol

i = 1 – Seasonal
2 – Extended Summer
3 – Permanent Residents

TCD_t = total annual cottage-days associated with the cottages in the subdivision in year t, i.e. predicted cottage-days per cottage (Equation 4.2) • number of cottages;

$P_t(i)$ = proportion of total cottage-days associated with cottage typology i in year t (Table 4.1); and

HSIZE(i) = average household size for typology i (Table 4.1).

The Water Quality Submodel requires user-days on a monthly basis. Since cottages within each typology group have different monthly use patterns, the allocation of total user-days to each month, accomplished as follows, will reflect these variations in cottage use.

$$\text{total monthly user-days (m)} = \sum_{i=1}^{3} TCD_t \cdot P_t(i) \cdot HSIZE(i) \cdot FRAC(i,m) \quad (4.4)$$

where FRAC(i,m) = proportion of total annual cottage use (user-days) allocated to month m for typology i (Figure 4.2).

TCD_t, $P_t(i)$, HSIZE(i) are defined in Equation 4.3

As the land use equations were developed from survey data, the increased cottage use associated with conversion from seasonal to permanent residences and from permanent to seasonal are included in the predictions of cottage use. Therefore, the historical rates of cottage conversion are implicit in the Land Use Submodel. However, if local conditions suggest that an unusually high (or low) conversion rate is likely to occur, such as might result from new employment opportunities, an appropriate conversion rate can be implemented in the model.

The user would specify an annual rate of transition from typology groups 1 and 2 (spring, summer and autumn users) to typology group 3 (permanent residents), i.e. the rate of cottage conversion. If the proportion of permanent users exceeds 0.6, the annual rate of transition is set to zero, i.e. cottages used all year will not exceed 60% of the total. The consequence of a change in the typology proportion is a disproportionate change in the total cottage-days associated with each typology. This occurs because cottages in the permanent residents group are occupied for more days during the year than those in the other typology groups (Table 4.1).

Table 4.1 Average number of days a cottage is occupied per year (CDAY) and average household size (HSIZE) for each cottage typology group (i)

Cottage Typology Group (i)	CDAY(i)	HSIZE(i)
1 = Seasonal	71.0	3.55
2 = Extended Summer	175.2	2.63
3 = Permanent Residents	363.1	2.55

4.3 TIME FRAME FOR PREDICTIONS

When the model is applied, it is important that the predictions remain valid for as long as possible — ideally, for the life of the cottages. Realistically, this is not attainable but it is possible to take policies and plans for the future into account in assigning values to the travel mode variables and in selecting an appropriate benchmark lake. For example, if the proposed subdivision has no access road at present but an approved transportation plan for the area provides for a road, then the travel mode would be recorded as "car" for all or part of the year. If, on the other hand, the transportation plan shows no road, then the travel mode would be recorded as "boat". Similarly, where an official plan indicates that permanent use may be prohibited and the zoning by-law specifies a "limited services" district for the area in which the proposed subdivision is located, it must be assumed that the road would be closed in winter. This would be taken into account in the choice of a benchmark lake.

The land use equations rely on existing cottage use patterns, which were established over time. The Land Use Component recommends periodic monitoring to provide a factual basis for judging whether the extent or rate of change merits a new survey.

4.4 ALLOCATION OF USER-DAYS TO TYPES OF SEWAGE DISPOSAL

Associated with each simulated cottage development on the lake is a specification of the mode of sewage disposal. This information is available from the subdivision proposal. Provisions are made for three kinds of disposal systems: lagoon, septic system, and holding tank. Pit privies are included with septic systems as both release sewage effluent into the soil. For the Water Quality Submodel, the predicted number of user-days must be allocated to each sewage disposal type, on a monthly basis, to provide data for estimating the annual amount of cottage-generated phosphorus. The allocation is calculated as follows:

$$\text{monthly sewage user-days}(ij) = \sum_{k=1}^{NDEV} TMUD_t(i) \cdot PCOTT_t(k) \cdot STYPE(k,j) \quad (4.5)$$

where
- NDEV = number of subdivisions;
- $TMUD_t(i)$ = total user-days in month (i), in year (t) (from Equation 4.4);
- $PCOTT_t(k)$ = number of cottages in subdivision (k), in year (t); and
- STYPE(k,j) = proportion of cottages in subdivision (k) using sewage disposal type (j) where 1 = lagoon, 2 = septic system, 3 = holding tank.

4.5 COTTAGE-DAYS FOR FISHING SEASONS

The Fisheries Submodel requires the total number of cottage-days for the summer (May – September) and winter (January – March) fishing seasons as part of the calculation of fishing effort. This is computed simply as the sum of the monthly information over the relevant periods.

4.6 NUMBER OF SWIMMERS

The number of swimmers at public or common beaches is required by the Water Quality Submodel, in order to predict the proportion of beach water samples with *Pseudomonas aeruginosa* (PsA), the pathogen that causes human ear infections. In the current submodel, two approaches are provided for estimating the number of swimmers in each month:

1) The first approach is to estimate swimmer density along the entire lakeshore, based on the total number of cottages on the lakeshore. The following equation is applied in this case to predict the maximum number of swimmers (MAXSWIM):

$$MAXSWIM = NO.\ COTT \cdot POCC(i) \cdot PSWIM2(i) \cdot UCOTT(i) \cdot USWIM(i) \quad (4.6)$$

where
- NO. COTT = total number of lakeshore cottages;
- POCC(i) = proportion of cottages occupied on day of highest cottage use in summer month i;
- PSWIM2(i) = proportion of cottages with swimmers on day of highest cottage use in month i;
- UCOTT(i) = average household size for cottages occupied on day of highest cottage use in month i; and
- USWIM(i) = proportion of swimmers (from cottages) actually swimming between 11:00 a.m. and 2:00 p.m.

2) The second approach focusses on common beaches, each identified with the subdivision they serve. The number of swimmers is based on the proportion of cottages in the subdivision with swimmers who use the common beach. The following modification of Equation 4.6 is used to predict the maximum number of swimmers at a common beach in subdivision kx (MAXSWIMB):

$$MAXSWIMB = COTI(kx) \cdot POCC(i) \cdot PSWIM(i) \cdot UCOTT(i) \cdot USWIM(i) \quad (4.7)$$

where
- kx = subdivision number;
- COTI(kx) = number of cottages in subdivision kx;
- i = months 6-9 (June – September); and
- PSWIM(i) = proportion of cottages with swimmers at a public or common beach on day of highest cottage use in month (i).

POCC, UCOTT and USWIM are defined in Equation 4.6.

The values used in the equations and the sources of these data are listed in Table 4.2. The occupancy data (POCC) and household size (UCOTT) vary by month. The last term, proportion of swimmers (from cottages) actually swimming between 11 a.m. and 2 p.m. (USWIM) incorporates two factors: distribution of swimmers throughout the day, and people in the water versus people on the beach. Additional terms could be used to handle an estimate of the proportion of swimmers who put their ears under water and the ratio of cottager swimmers to non-cottager swimmers for the lake.

Table 4.2 Parameter estimates used to calculate the number of swimmers at public or common beaches and in the water along the shore, for the selected day of highest cottage use in each summer month.

MONTH[1]	POCC[2]	PSWIM[3]	PSWIM2[4]	UCOT T[5]	USWIM[6]
June	0.66	0.32	0.96	2.1	0.5
July	0.87	0.32	0.96	3.6	0.5
August	0.89	0.32	0.96	3.6	0.5
September	0.84	0.32	0.96	3.3	0.5

[1] Day of highest use in the month is associated with the last two weekends in June, Dominion Day in July, the Civic Holiday in August and Labor Day in September.

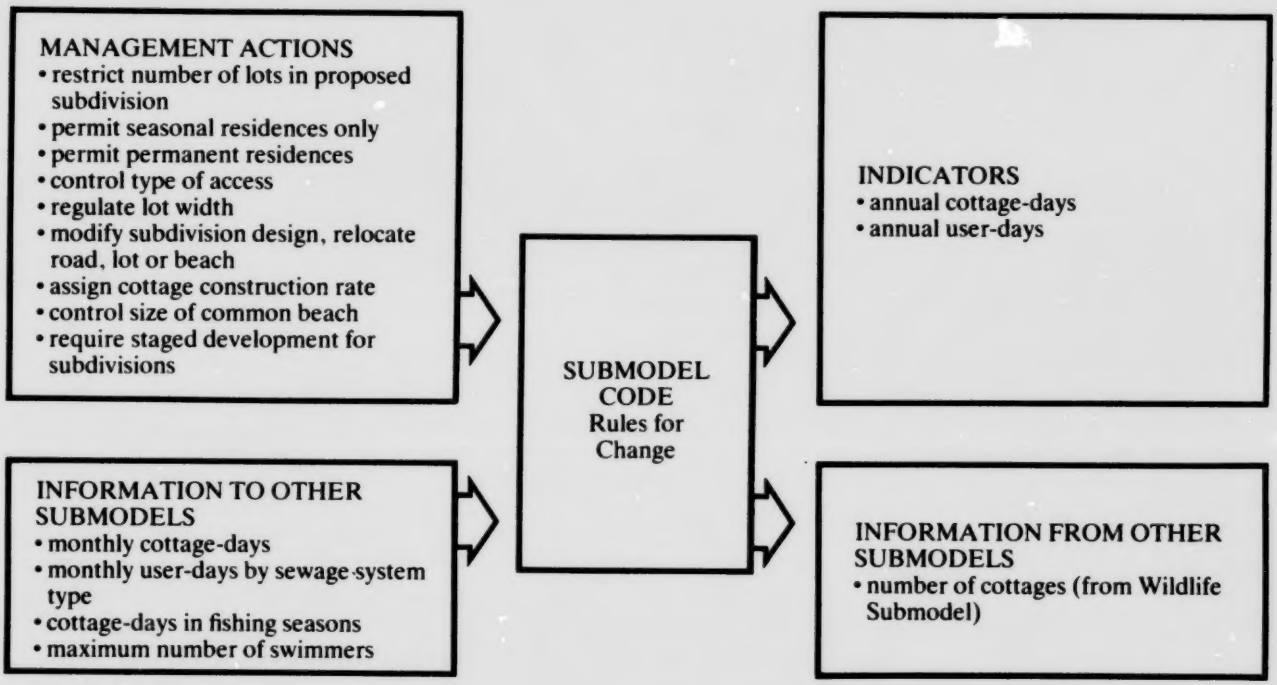
[2-5] Land Use Component estimate, based on 1978 Survey of Lakeshore Residents.

[6] Microbiology Component estimate, based on knowledge of study lakes.

Information on maximum swimmer density is used in the Water Quality Submodel to calculate the proportion of water samples with PsA bacteria, for the months June to September. The frequency of occurrence of the PsA bacteria in the water, in the area used for swimming, affects the amount of swimmer contact with these organisms and the risk of contracting the ear infection *otitis externa*. If a common beach is associated with subdivision kx, the model estimates the frequency of occurrence of the bacteria at a specific beach. If there is no beach associated with a particular subdivision, the indicator becomes the lake shoreline background PsA value.

4.7 SUMMARY

The Land Use Submodel provides a measure of cottage use, the major source of environmental impact from lakeshore cottage development. The submodel can simulate conditions on a lake with existing and proposed cottages and can alter these conditions in accordance with user-specified management actions. The Land Use Submodel generates the key land use indicators as well as specific information required by other submodels to determine the impact on the environment. The following input-output box diagram summarizes these submodel elements.


MANAGEMENT ACTIONS
• restrict number of lots in proposed subdivision
• permit seasonal residences only
• permit permanent residences
• control type of access
• regulate lot width
• modify subdivision design, relocate road, lot or beach
• assign cottage construction rate
• control size of common beach
• require staged development for subdivisions
INFORMATION TO OTHER SUBMODELS
• monthly cottage-days
• monthly user-days by sewage system type
• cottage-days in fishing seasons
• maximum number of swimmers
SUBMODEL CODE
Rules for Change
INDICATORS
• annual cottage-days
• annual user-days
INFORMATION FROM OTHER SUBMODELS
• number of cottages (from Wildlife Submodel)

5. WATER QUALITY SUBMODEL

The Water Quality Submodel is divided into two parts: one designed to predict the nutrient level, or trophic status, of the lake and the other concerned with the health-related microbiology of lake water.

The focus of the trophic status portion of the submodel is phosphorus, as it is the nutrient most frequently controlling algae and plant production in north temperate lakes. High phosphorus levels are associated with the pollution of lakes and the decrease in water quality, i.e. water clarity and dissolved oxygen. The microbiology part of the submodel predicts the presence in lake water of the pathogen *Pseudomonas aeruginosa*. It is the causal organism of the human ear disease, *otitis externa* and is common enough in recreational lakes to be a public health concern. The major events in the Water Quality Submodel appear in the flow chart (Figure 5.1).

5.1 SUBMODEL TIME-STEP

The Water Quality Submodel is capable of making seasonal or annual predictions. A seasonal time-step is preferable, as this permits examination of the interactions of different cottage typologies and/or sewage treatment systems (e.g. lagoons with release in the spring) with seasonal patterns of flushing and natural phosphorus loading.

Indicators dependent on phosphorus concentrations, i.e. algal biomass, chlorophyll *a*, Secchi depth, and zooplankton biomass, are average seasonal values since there is insufficient understanding to justify monthly calculations.

The four seasons (relative to deep lake water conditions) used in the submodel are:

(a) Spring (March 16 – May 15)
(b) Summer (May 16 – October 31) stratified lake
(c) Fall (November 1 – November 30)
(d) Winter (December 1 – March 15) non-stratified lake

The lengths and starting times of these seasons vary somewhat with the size of the lake and other physical parameters. At present, the submodel uses the average dates listed above, but it has been structured to permit the user to specify the duration of each season.

5.2 TOTAL PHOSPHORUS

Lake phosphorus concentration is the net result of natural and artificial inputs, retention in the lake sediments and release through outflow streams (Figure 5.2). Total phosphorus predictions are based on the assumption that the lake is a homogeneous water mass. In fact, thermal stratification produces concentration gradients and mixing delays.

From a knowledge of the geology and land use in the drainage basin, an estimate is made of the total phosphorus exported per unit area which, combined with the drainage area, provides an estimate of the total phosphorus supplied to the lake from the drainage basin. To calculate the total natural phosphorus supply to the lake, the drainage basin phosphorus is added to the phosphorus in precipitation falling directly on the lake, and the phosphorus contribution from inflow streams.

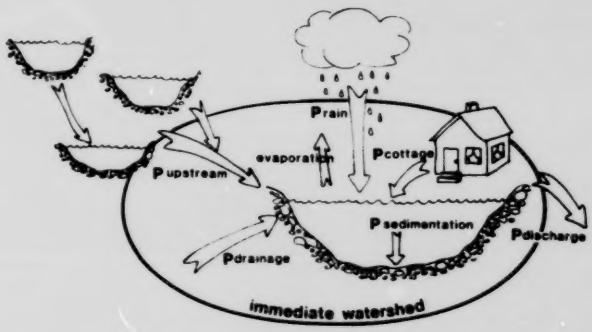


Figure 5.2 Input and output of phosphorus

The artificial (cottage-generated) phosphorus supply is calculated from the yearly per capita estimate of phosphorus in household sewage (0.81 kg/yr) and the predicted number of user-days for cottages on a given lake. The proportion of the cottage-generated phosphorus that will reach the lake is related to the number of user-days associated with each type of sewage disposal system. Holding tanks, for example, release no phosphorus to the lake because the tanks are pumped out periodically and the sludge is removed to treatment plants outside the watershed. Sewage lagoons, which are not commonly used for cottage development, are settling basins that are partially drained in the spring, at which time about 15% of the sewage-phosphorus is released. Septic and aerobic systems and pit privies, the dominant sewage disposal systems, release effluent to the soil and subsurface water. The amount of phosphorus reaching the lake is calculated from the phosphorus binding capacity of the soil reservoir and the phosphorus leakage rate.

Changes in the lake total phosphorus concentration are calculated according to the following equation, adapted from Dillon and Rigler (1975):

$$\Delta [P] = \frac{(P_{RAIN} + P_D + P_{UP} + P_{CL})}{V} - \delta [P] - \rho [P] \quad (5.1)$$

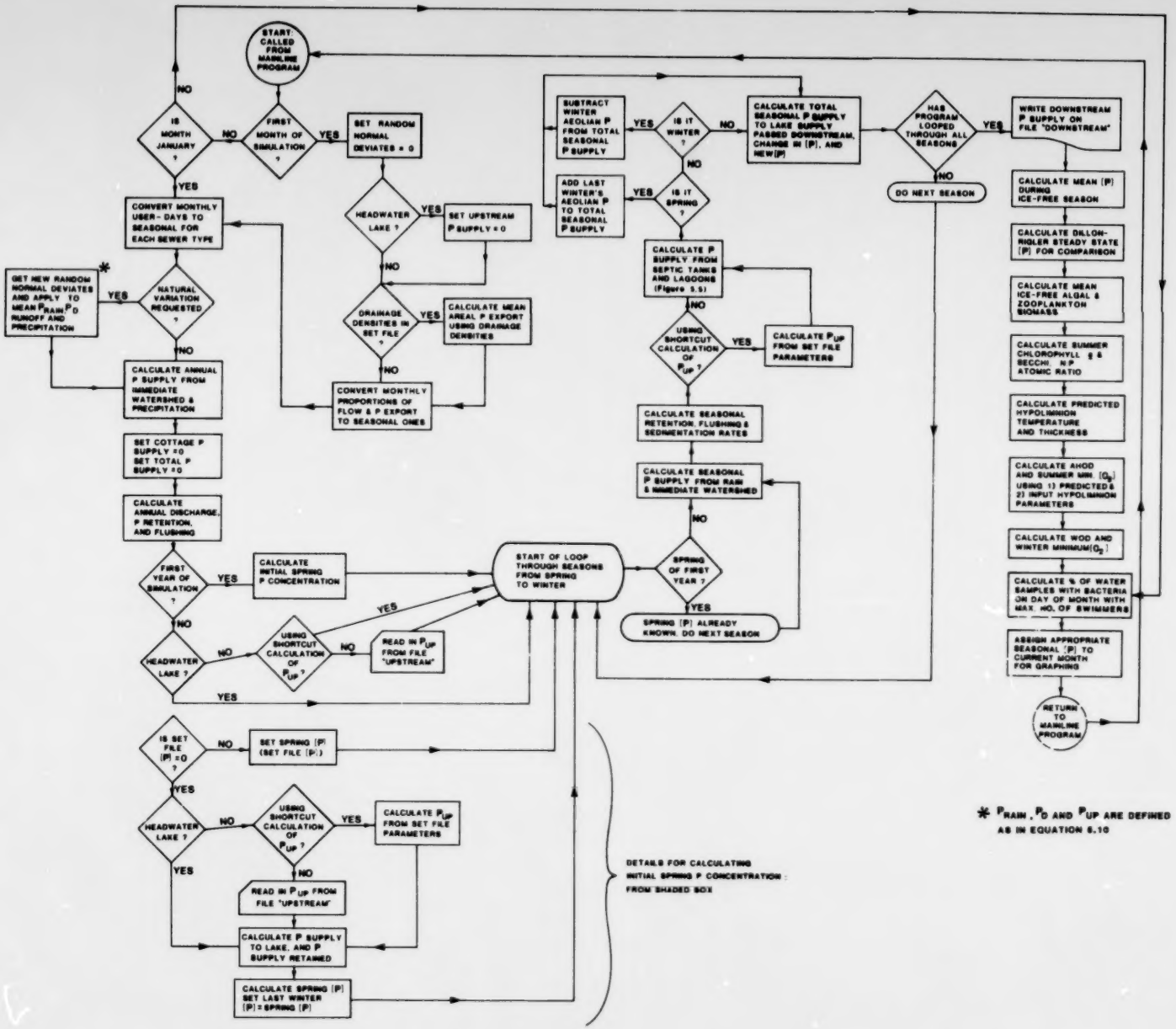

START CALLED FROM MAINLINE PROGRAM
IS MONTH JANUARY ?
NO
YES
FIRST MONTH OF SIMULATION ?
YES
SET RANDOM NORMAL DEVIATES = 0
CONVERT MONTHLY USER-DAYS TO SEASONAL FOR EACH SEWER TYPE
GET NEW RANDOM NORMAL DEVIATES AND APPLY TO MEAN P_{RAIN}, P_D RUNOFF AND PRECIPITATION
NATURAL VARIATION REQUESTED ?
CALCULATE ANNUAL P SUPPLY FROM IMMEDIATE WATERSHED & PRECIPITATION
SET COTTAGE P SUPPLY = 0
SET TOTAL P SUPPLY = 0
CALCULATE ANNUAL DISCHARGE, P RETENTION, AND FLUSHING
FIRST YEAR OF SIMULATION ?
CALCULATE INITIAL SPRING P CONCENTRATION
HEADWATER LAKE ?
USING SHORTCUT CALCULATION OF P_{UP} ?
READ IN P_{UP} FROM FILE "UPSTREAM"
IS SET FILE (P) = 0 ?
SET SPRING (P) (SET FILE (P))
USING SHORTCUT CALCULATION OF P_{UP} ?
CALCULATE P_{UP} FROM SET FILE PARAMETERS
READ IN P_{UP} FROM FILE "UPSTREAM"
CALCULATE P SUPPLY TO LAKE, AND P SUPPLY RETAINED
CALCULATE SPRING (P) SET LAST WINTER (P) = SPRING (P)
HEADWATER LAKE ?
SET UPSTREAM P SUPPLY = 0
DRAINAGE DENSITIES IN SET FILE ?
CALCULATE MEAN AREAL P EXPORT USING DRAINAGE DENSITIES
CONVERT MONTHLY PROPORTIONS OF FLOW & P EXPORT TO SEASONAL ONES
START OF LOOP THROUGH SEASONS FROM SPRING TO WINTER
SUBTRACT WINTER AEOLIAN P FROM TOTAL SEASONAL P SUPPLY
ADD LAST WINTER'S AEOLIAN P TO TOTAL SEASONAL P SUPPLY
IS IT WINTER ?
IS IT SPRING ?
CALCULATE P SUPPLY FROM SEPTIC TANKS AND LAGOONS (Figure 5.5)
USING SHORTCUT CALCULATION OF P_{UP} ?
CALCULATE P_{UP} FROM SET FILE PARAMETERS
CALCULATE SEASONAL RETENTION, FLUSHING & SEDIMENTATION RATES
CALCULATE SEASONAL P SUPPLY FROM RAIN & IMMEDIATE WATERSHED
SPRING OF FIRST YEAR ?
SPRING (P) ALREADY KNOWN. DO NEXT SEASON
CALCULATE TOTAL SEASONAL P SUPPLY TO LAKE SUPPLY PASSED DOWNSTREAM, CHANGE IN (P), AND NEW (P)
HAS PROGRAM LOOPED THROUGH ALL SEASONS
DO NEXT SEASON
WRITE DOWNSTREAM P SUPPLY ON FILE "DOWNSTREAM"
CALCULATE MEAN (P) DURING ICE-FREE SEASON
CALCULATE DILLON-RIGLER STEADY STATE (P) FOR COMPARISON
CALCULATE MEAN ICE-FREE ALGAL & ZOOPLANKTON BIOMASS
CALCULATE SUMMER CHLOROPHYLL & SECCHI, N:P ATOMIC RATIO
CALCULATE PREDICTED HYPOLIMNION TEMPERATURE AND THICKNESS
CALCULATE AHOD AND SUMMER MIN. (O_2) USING 1) PREDICTED & 2) INPUT HYPOLIMNION PARAMETERS
CALCULATE WOD AND WINTER MINIMUM (O_2)
CALCULATE % OF WATER SAMPLES WITH BACTERIA ON DAY OF MONTH WITH MAX. NO. OF SWIMMERS
ASSIGN APPROPRIATE SEASONAL (P) TO CURRENT MONTH FOR GRAPHING
RETURN TO MAINLINE PROGRAM
DETAILS FOR CALCULATING INITIAL SPRING P CONCENTRATION FROM SHADED BOX
* P_{RAIN}, P_D AND P_{UP} ARE DEFINED AS IN EQUATION 5.10

Figure 5.1 Water Quality Submodel flow chart

where $\Delta [P]$ = change in total phosphorus concentration ($mg \cdot m^{-3}$) over a given season;
P_{RAIN} = supply of total phosphorus in precipitation during the given season (mg);
P_D = natural supply of total phosphorus to the lake from its immediate drainage basin, during the given season (mg);
P_{UP} = supply of total phosphorus from lakes upstream during the given season (mg);
P_{CL} = supply of total phosphorus from cottages that reaches lake during the given season (mg);
V = volume of water in lake (m^3);
$[P]$ = previous season's total phosphorus concentration ($mg \cdot m^{-3}$);
δ = phosphorus sedimentation rate ($season^{-1}$); and
ρ = lake flushing rate ($season^{-1}$).

5.3 PRECIPITATION P LOAD

The annual precipitation (aeolian) supply of P is calculated by randomly choosing a number from a normal distribution with a mean of 37.3 $mg \cdot m^{-2} \cdot yr^{-1}$ and a standard deviation compiled from four years of aeolian P data (Scheider, pers. comm. 1982). If no annual variation is desired (useful for first-cut model runs), the standard deviation is set to zero, as in the example in Appendix C. When natural variation in the model is switched on, precipitation, runoff, nutrient loads from precipitation and watershed export of nutrients all become stochastic variables, i.e. varying in a quasi-random fashion to mimic natural occurrence.

The monthly proportions of the annual phosphorus supply, based on data (1976-80) collected by the Trophic Status Component (Figure 5.3), are converted to seasonal proportions. The precipitation phosphorus supply to the lake during the winter is accumulated as phosphorus stored in snow on the ice cover. It is then added, as snow melt, to the aeolian phosphorus falling on the lake in the spring.

5.4 IMMEDIATE WATERSHED P LOAD

At present the submodel calculates the export of P from the immediate watershed by one of two methods, depending upon whether information is available on the watershed sub-basin drainage. Where possible, the P export from each sub-basin is calculated by the regression equation[1] of Kirchner (1975):

$$\text{Phosphorus export } (mg \cdot m^{-2} \cdot yr^{-1}) = 1.32 + 5.54 \cdot \frac{\text{length of all streams (km)}}{\text{sub-basin area (km}^2\text{)}} \quad (5.2)$$

The total P supply from the specified sub-basins is calculated by multiplying the P export for each sub-basin by the area of the sub-basin and summing over all sub-basins. For the sections of the watershed that are not drained by streams, the average of the sub-basin P export values is applied to the surface area. The total P supplied from drainage is the sum of the supplies from all parts of the immediate drainage basin. The above method assumes that the watershed is forested and underlain by igneous rock.

The annual drainage basin P supply is prorated over the months and seasons according to Figure 5.4 which is based on data (1976-80) provided by Scheider (pers. comm. 1982).

The alternative method is to apply an average P export value for areas underlain by igneous rock. Depending on whether the watershed is forested or consists of forest plus pasture (i.e. cleared on more than 15% of the watershed), the P export values of 4.7 $mg \cdot m^{-2} \cdot yr^{-1}$ and 10.2 $mg \cdot m^{-2} \cdot yr^{-1}$, respectively, are used in the model (Dillon and Rigler 1975).

[1] This equation will be replaced by an equation recently developed by the Trophic Status Component (Dillon, pers. comm. 1982) which was not available in time for inclusion in this version of the OLCSM. The simplified version of the new equation predicts the annual gross phosphorus export from the watershed as a function of peat (% area), grade (% area), bedrock (% area) and outwash plain (% area).

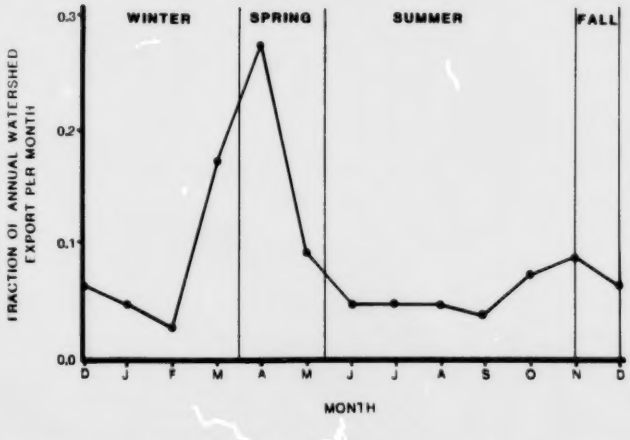


Figure 5.3 Mean monthly distribution of bulk precipitation phosphorus supply over 4-year period (1976-80)

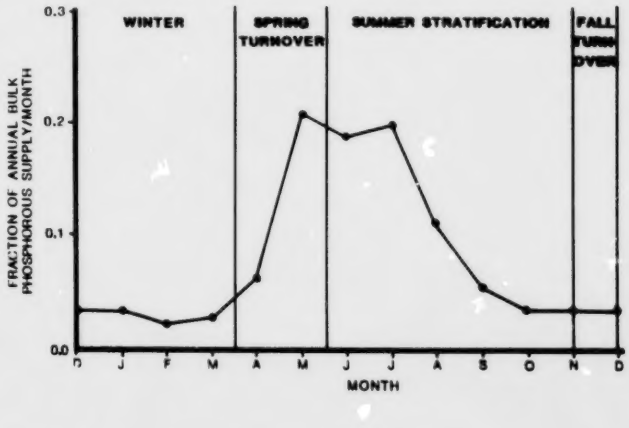


Figure 5.4 Mean monthly distribution of watershed phosphorus export over 4-year period (1976-80)

5.5 UPSTREAM P LOAD

Where development is proposed for a watershed containing more than one lake, phosphorus balance calculations proceed from the highest (headwater) drainage basin down to the lowest. Predictions of trophic status indicators are made for each lake in the chain. From the initial conditions and proposed developments on a headwater lake, a time series of phosphorus supply released downstream is calculated and stored. These data then provide the upstream P supply for the simulation of conditions (over the same time period) in the next lake downstream. The time series of phosphorus releases from the second lake serves as the upstream P supply for the third lake, and so on.

One advantage of this approach is the ability to examine downstream impacts of particular policies. For example, development on a well-flushed headwater lake may not significantly increase phosphorus concentrations there, but could have a decided impact on a larger, poorly drained, downstream lake. The model is capable of simulating any configuration of connecting lakes.

Calculation of the upstream P supply by the above method is only feasible when information on lake and watershed morphometry, as well as present and future land use, is available for each lake in the chain. Since such information is often not available, a "short-cut" approach can be used to estimate upstream contributions of phosphorus. Upstream supplies are calculated from two user-specified parameters: the mean concentration of phosphorus in the next lake upstream, and the proportion of watershed runoff that drains through these upstream lake . The seasonal P supply from upstream (P_{UP}) is then:

$$P_{UP} = YQ * FUP * FQ * [P]_{UP} \quad (5.3)$$

$(mg \cdot season^{-1})$

where YQ = annual discharge through lake $(m^3 \cdot yr^{-1})$;
FUP = fraction of watershed drainage through upstream lakes;
FQ = fraction of YQ occurring in a given season; and
$[P]_{UP}$ = mean phosphorus concentration in upstream lakes $(mg \cdot m^{-3})$.

5.6 COTTAGE P LOAD

At present, calculations of the cottage phosphorus supply to the lake are performed in two steps:

(a) calculation of the amount of phosphorus generated by the lakeshore cottages, depending on the types of sewage disposal systems (Table 5.1);
(b) calculation of the amount of phosphorus actually reaching the lake each season.

The total P generated by cottages each season (PCOTT) is calculated by:

$$PCOTT_i = 2191.8 \text{ mg} \cdot \text{user}^{-1} \cdot \text{day}^{-1} * \quad (mg \cdot season^{-1})$$

$$\sum_{i=1}^{12} USERM_i * (1\text{-}SEWRET_i) \quad (5.4)$$

where $USERM_i$ = user-days on sewage disposal method i in given season; and
$SEWRET_i$ = fraction of cottage-generated P removed (removal function) from watershed under method i.

The smaller the SEWRET value, the more P release is assumed. For example, for a lagoon system the SEWRET value is 0.85. Therefore 15% of the sewage phosphorus would be released. With respect to lagoons, the user can specify the season(s) during which the lagoon is to be emptied.

Table 5.1 Sewage disposal system categories

Type of system	Fraction of P supply removed from watershed (SEWRET)	Time of release to lake
1. Lagoon	0.85	any season (user defined)
2. Septic tank, aerobic system or pit privy	0.0	continuous
3. Holding tank	1.0	no release

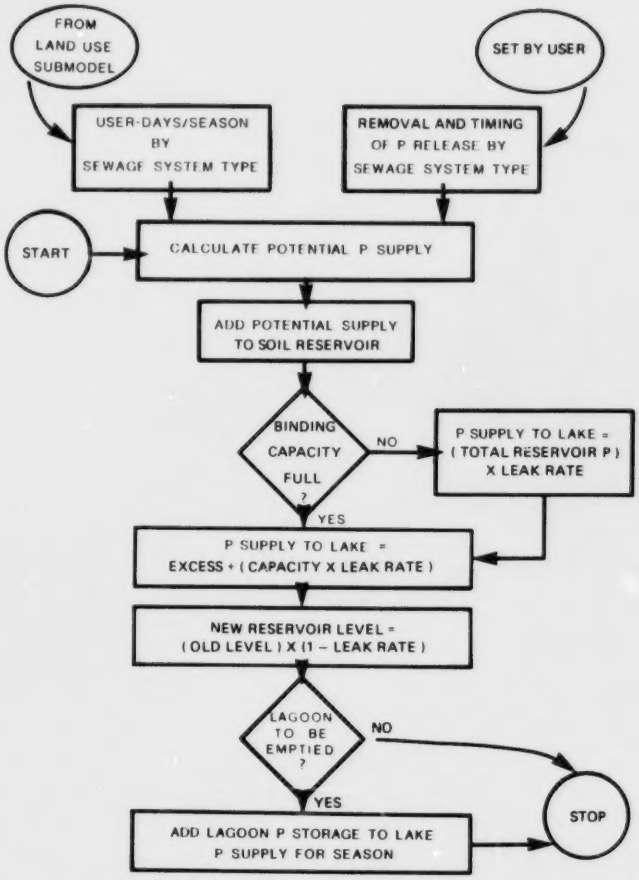

FROM LAND USE SUBMODEL
SET BY USER
USER-DAYS/SEASON BY SEWAGE SYSTEM TYPE
REMOVAL AND TIMING OF P RELEASE BY SEWAGE SYSTEM TYPE
START
CALCULATE POTENTIAL P SUPPLY
ADD POTENTIAL SUPPLY TO SOIL RESERVOIR
BINDING CAPACITY FULL ?
NO
P SUPPLY TO LAKE = (TOTAL RESERVOIR P) X LEAK RATE
YES
P SUPPLY TO LAKE = EXCESS + (CAPACITY X LEAK RATE)
NEW RESERVOIR LEVEL = (OLD LEVEL) X (1 – LEAK RATE)
LAGOON TO BE EMPTIED ?
NO
YES
ADD LAGOON P STORAGE TO LAKE P SUPPLY FOR SEASON
STOP

Figure 5.5 Algorithm for calculating seasonal phosphorus supply from cottages to lake

To explore the consequences of different soil types, the submodel allows the specification of a phosphorus binding capacity in the soil, expressed in kg of phosphorus binding capacity per cottage, and a transport or leakage rate from soil storage (RLEAK), expressed as a fraction of the capacity for each season. A maximum phosphorus binding capacity per cottage (2.4 kg phosphorus) equivalent to three years use by permanent residents was arbitrarily assigned as an initial condition. However, by setting RLEAK = 1, it was also assumed (for the base runs) that all the phosphorus within the soil storage would be transported to the lake within one year. Without modifying any of the assumptions, the base runs of the model represent a 'worst case' from the point of view of cottage phosphorus supply. The phosphorus actually transported to the lake in a given season is calculated according to the algorithm shown in Figure 5.5.

5.7 WATERSHED HYDROLOGY AND PHOSPHORUS RETENTION

The concentration of nutrients in lake water is the net result of the mass of material deposited in the lake, minus the material removed from the water column through flushing and sedimentation.

The annual outlet discharge YQ, in $m^3 \cdot yr^{-1}$, is calculated using the formula developed by Dillon and Rigler (1975):

$$YQ = [A_d * r + A_o (P_r - E_v)] * [10^4 \, m^2 \cdot ha^{-1}] \qquad (5.5)$$

where A_d = total drainage basin area including all upstream drainage (ha);
A_o = lake surface area (ha);
r = mean annual areal runoff ($m \cdot yr^{-1}$) (assumed value 0.4);
P_r = amount of annual precipitation (m) (assumed value 0.9); and
E_v = amount of annual evaporation (m) (assumed value 0.6).

If the total watershed area is greater than 10 times the lake surface area, the net increase in the lake water due to precipitation falling directly on the lake, $A_o(P_r - E_v)$, is negligible and is therefore omitted from the equation.

The phosphorus supply from drainage is calculated only for the lake's immediate watershed because P drainage through upstream lakes is included separately. The water loading for the lake is based on the entire drainage basin upstream of the lake. In Lake Boshkung, for example, the entire drainage basin is 63 times the area of the lake's immediate watershed. This contrasts with headwater lakes, such as Harp or Blue Chalk, where the immediate watershed is equal to the entire drainage basin.

When natural variation is invoked in the simulation, runoff and precipitation vary in the same direction as aeolian and watershed phosphorus supply. Evaporation remains constant since no information is available to indicate to what degree variation in evaporation is correlated with rainfall. The mean values for the variables listed above were obtained from Lakeshore Capacity Study data and from the literature (Dillon and Rigler 1975, Scheider 1978).

Annual discharge is converted to seasonal discharge from the monthly distribution (Figure 5.6) which was extracted from data provided by Scheider (1976-1980). The seasonal discharge divided by the lake volume yields the flushing rate, ρ, which is the number of times the lake's volume is completely replaced in that season. The ρ rate is an important determinant of the seasonal change in phosphorus concentration, as shown by Equation 5.1.

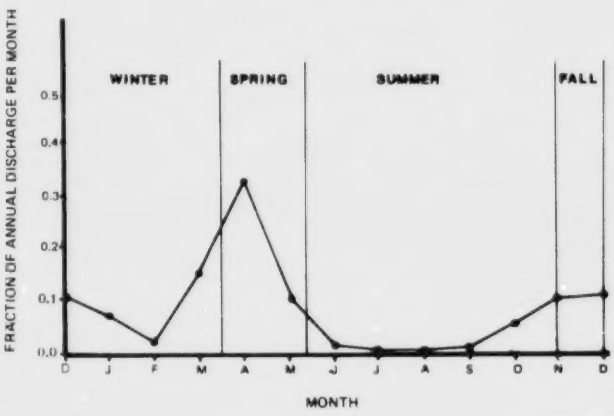


Figure 5.6 Mean monthly distribution of annual discharge over 4-year period (1976-80)

The other important parameter in Equation 5.1 is the phosphorus sedimentation rate, δ. Although δ is difficult to measure directly, it is related by Equation 5.6 to the empirically predictable retention coefficient, R, the fraction of the phosphorus supply not lost via outflow:

$$\delta = \frac{\rho R}{(1\text{-}R)} \quad \text{(Dillon and Rigler 1974)} \qquad (5.6)$$

Equation 5.6 is valid for any time-step, provided that R and ρ have been calculated for a similar time period. Prior to the development of the OLCSM, an annual time-step was used. Annual retention coefficients (YR) have been estimated using various empirical equations (Ostrofsky 1978), the simplest of which is:

$$YR = \frac{V}{V + YQS} \quad \text{(Dillon and Kirchner 1975)} \qquad (5.7)$$

where YR = annual phosphorus retention coefficient (rate) (proportion $\cdot yr^{-1}$);
V = annual phosphorus settling velocity ($m \cdot yr^{-1}$);
YQS = annual areal water loading = YQ/AREA ($m \cdot yr^{-1}$);
YQ = lake outlet discharge ($m^3 \cdot yr^{-1}$); and
AREA = lake surface area (m^2).

The original formulation[2] of Equation 5.7 had a constant value for V of 13.2. However, retaining this constant in the calculations produced highly inaccurate results. Therefore, an interim equation was developed which brought the model indicators more in line with the actual measurements used as a comparison. This formulation

[2] Dillon (pers. comm. 1982) has developed a better formula for the calculation of phosphorus retention. The new equation predicts phosphorus retention in a lake as a function of the lake flushing rate. This equation was not available in time for incorporation in this version of the OLCSM.

was based on a stepwise forward inclusion regression procedure (SAS 1979) with data from eight Trophic Status Component study lakes which have no lakeshore development. The following equation was derived and is presently used in the model:

$$V = 0.0074\ ALD + 1.927 \quad (5.8)$$

where V = annual phosphorus settling velocity ($m \cdot yr^{-1}$);
ALD = [YPLOAD/AREAL * 10,000] * DEPTH;
YPLOAD = total phosphorus supply to lake ($mg \cdot yr^{-1}$);
AREAL = lake surface area (ha); and
DEPTH = mean lake depth (m).

The seasonal retention coefficient (R) was estimated by the equation:

$$R = \frac{RFIT}{RFIT + QS} \quad (5.9)$$

where QS = seasonal areal water loading = Q/AREA;
Q = seasonal discharge = YQ * FQ (Equation 5.4);
AREA = lake surface area (m^2); and
RFIT = net rate of sedimentation of total phosphorus (in metres per season). This may be interpreted as a sinking rate through the water column.

Since no empirical relationship existed for seasonal retention coefficients, the RFIT values were fitted by trial and error matching of the steady state concentrations predicted by the seasonal time-step submodel and predicted by the equation:

$$P^* = \frac{J(1-YR)}{YQ} \quad \text{(Schneider 1978)} \quad (5.10)$$

where P^* = steady state concentration ($mg \cdot m^{-3}$); and
J = supply to lake ($mg \cdot yr^{-1}$) summed over 4 seasons. This value includes ($P_{RAIN} + P_D + P_{UP} + P_{CL}$)

where P_{RAIN} = aeolian phosphorus;
P_D = phosphorus from drainage;
P_{UP} = phosphorus from upstream; and
P_{CL} = phosphorus from cottages.
YR and YQ are defined in Equation 5.7.

Based on an understanding of the relative rates of sedimentation, and the parameter fitting, the following proportions are applied in apportioning the annual settling velocity to the four seasons.

Season	Proportion of annual sedimentation RFIT	Settling Velocity V assuming an annual V of 13.2 $m \cdot yr^{-1}$
Spring	0.00	0.00
Summer	0.64	8.44
Fall	0.04	0.53
Winter	0.32	4.23

If Equation 5.9 is substituted in Equation 5.6, the sedimentation rate for a season is equal to RFIT for that season divided by the mean depth of the lake. Not surprisingly, deep lakes lose phosphorus to the bottom sediments at a slower rate than shallow lakes.

5.8 ALGAL BIOMASS AND CHLOROPHYLL *a*

A weighted average of the total phosphorus concentrations in spring, summer and fall is used to predict mean algal biomass during summer stratification. The submodel uses a relationship (Figure 5.7) based on measurements in the Kawartha Lakes – Bay of Quinte region, reported by Nicholls and Dillon (1978), as no such relationship has been developed for Ontario lakes in the Precambrian Shield.

The mean summer chlorophyll *a* concentration is estimated using the Dillon-Rigler (1975) formulation (Figure 5.8). Their equation uses the spring phosphorus concentration in the formula:

$$\log CHLOR = 1.45 \log SCPLK(1) - 1.14 \quad (5.11)$$

where CHLOR = chlorophyll *a* concentration ($\mu g \cdot L^{-1}$); and
SCPLK(1) = spring phosphorous concentration ($\mu g \cdot L^{-1}$).

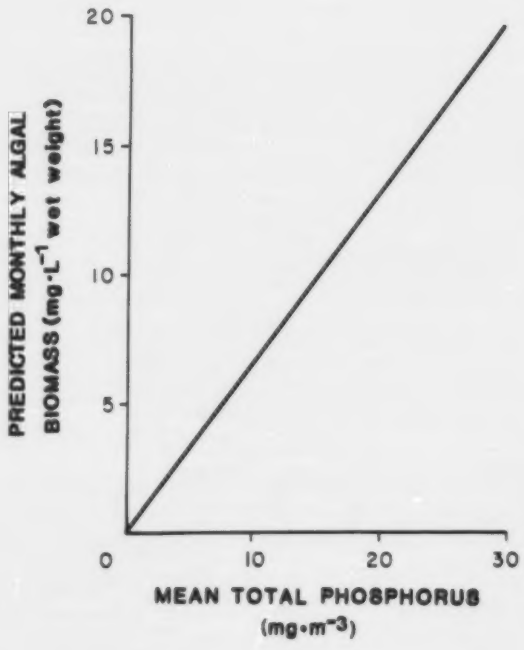


Figure 5.7 Mean algal biomass and mean total phosphorus concentration during ice-free months (from Nicolls and Dillon 1978)

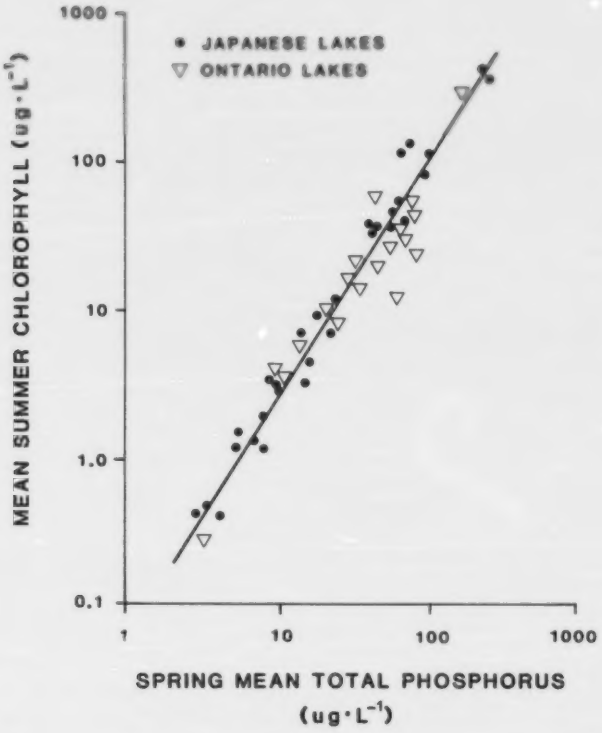


Figure 5.8 Relationship between mean spring total phosphorus and mean summer chlorophyll *a* (from Lorenzen 1978)

5.9 SECCHI DEPTH

Transparency, as measured by Secchi disc depth, is presently estimated from the chlorophyll *a* concentration (Scheider, pers. comm.) by:

$$\text{SECCHI} = \frac{5.21}{\text{CHLOR}^{0.41}} \qquad (5.12)$$

where SECCHI = mean summer Secchi depth (m); and
CHLOR = chlorophyll *a* concentration ($\mu g \cdot L^{-1}$).

5.10 EDIBLE ALGAL BIOMASS

As a lake becomes eutrophic, a decreasing proportion of the algal biomass is consumed by zooplankton. This is because the ratio between P and nitrogen is disturbed enough to cause growth of inedible algal species. Therefore, the food base for planktivorous fish cannot be assumed to continue to increase linearly with increasing nutrients. A nitrogen balance equation following the form of Equation 5.1 (neglecting algal fixation of atmospheric nitrogen) is used to predict approximate changes in nitrogen concentration:

$$\Delta[N] = \frac{(N_{RAIN} + N_D + N_{UP} + N_{CL})}{V} - \delta[N] - \rho[N] \qquad (5.13)$$

where $\Delta[N]$ = change in total N concentration ($\mu g \cdot L^{-1}$) over a given season;
N_{RAIN} = supply of total nitrogen in precipitation during the given season (mg);
N_D = natural supply of nitrogen from immediate drainage basin during the given season (mg);
N_{UP} = supply of nitrogen from lakes upstream during the given season (mg);
N_{CL} = supply of nitrogen from cottages reaching the lake during the given season ($\mu g \cdot L^{-1}$);
δ and ρ = were assumed to be the same for N as for P;
[N] = previous season's nitrogen concentration ($\mu g \cdot L^{-1}$); and
V = volume of lake (m^3).

The development of blue-green algal blooms (mostly inedible) is assumed to be dependent upon (a) lake phosphorus concentrations of at least 10 $mg \cdot m^{-3}$, and (b) N:P atomic ratios[3] less than 14. Figure 5.9 illustrates these hypotheses, with the probability of blooms varying directly with phosphorus concentration and inversely with the N:P ratio (Scheider, pers. comm. 1980). Phosphorus concentrations between 10 and 30 are given lines of intermediate slope.

Total nitrogen concentration is set initially to 664 $mg \cdot m^{-3}$, which together with the initial total phosphorus concentration of 15 $mg \cdot m^{-3}$, yields a starting N:P atomic ratio of 20:1.

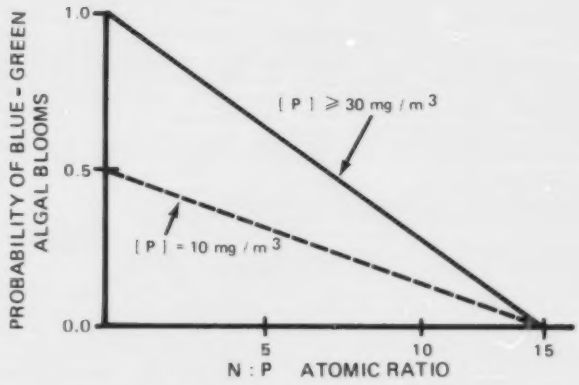


Figure 5.9 Probability of blue-green algal blooms for given N:P ratios

5.11 ZOOPLANKTON

The mean density of zooplankton during the summer lake stratification period is predicted from the mean ice-free phosphorus concentration [P] (a weighted average of spring, summer and fall concentrations) by the regression equation:

$$\text{mean zooplankton biomass } (mg \cdot m^{-3} \text{ dry wt.}) = 4.5 \cdot [P] + 38 \qquad (5.14)$$

This equation is based on Ministry of the Environment data obtained from lakes in the Kawartha Lakes – Bay of Quinte region. Since the carrying capacity for trout is presently predicted directly from lake nutrient concentration, bypassing the zooplankton level, this prediction is calculated but not used in the Fisheries Submodel. However, it remains in the submodel because of its potential future use.

[3] atomic ratio = 0.45 × weight ratio

5.12 OXYGEN

The areal hypolimnetic oxygen deficit (AHOD) is calculated each year using the multiple regression equation developed by Cornett and Rigler (1979):

$$AHOD = -277 + 0.5\,R_p + 5.0\,T_H^{1.7\alpha} + 150 \ln(Z_H) \qquad (5.15)$$

where AHOD = areal hypolimnetic oxygen deficit (mg $O_2 \cdot m^{-2} \cdot day^{-1}$);
R_p = areal phosphorus retention ($mg \cdot m^{-2} \cdot yr^{-1}$)
= [P] * YQ * YR/(AREA * (1-YR));
[P] = mean ice-free phosphorus concentration ($mg \cdot m^{-3}$);
YQ = annual outflow discharge ($m^3 \cdot yr^{-1}$);
YR = annual phosphorus retention coefficient (range 0-1);
AREA = area of lake (m^2);
T_H = mean temperature of the hypolimnion (°C);
ln = natural logarithm; and
Z_H = mean thickness of the hypolimnion (m).

A second equation developed by Charlton (1980) is also programmed into the model. It differs from Equation 5.15 in that chlorophyll *a* is used instead of phosphorus retention.

$$AHOD = 3.80 * [FCHLOR * (Z_H/(50. + Z_H)) * 2((T_H - 4.0)/10)] + .12 \qquad (5.16)$$

where FCHLOR = $1.15\,(CHLOR^{1.33})/(9.0 + 1.15 * CHLOR^{1.33})$
= chlorophyll *a* factor derived from the Equation 5.11.
Z_H and T_H are defined in Equation 5.15.

A switch is provided so that the user can work with either equation, permitting a comparison of the results of the two methods (Appendix B).

5.12.1 HYPOLIMNION TEMPERATURE AND THICKNESS

Two approaches are used in estimating the mean temperature and thickness of the hypolimnion.

The direct approach requires T_H and Z_H as input data and assumes that they remain constant over time. This method can be used on any lake for which temperature profile data over the summer stratification season are available.

The indirect method uses a hypothetical set of curves to predict mean hypolimnetic temperature and thickness (Figures 5.10 and 5.11, respectively). The mean temperature of the hypolimnion is assumed to be inversely proportional to the maximum depth of the lake, and directly proportional to the Secchi depth. This is because greater transparency results in increased heating of the hypolimnion. These relationships are represented by the equation:

$$T_H = 4.0 + (50.0 - Z_{MAX}) * 0.04 * SECCHI \qquad (5.17)$$

where T_H = mean temperature of the hypolimnion (°C)
Z_{MAX} = maximum depth (m); and
SECCHI = mean summer Secchi depth (m).

The hypolimnetic temperature is plotted (Figure 5.10) against Secchi depth for various maximum depths; a maximum temperature of 25°C is assumed. The effect of this relationship on the AHOD calculation is that nutrient enrichment will cause lowered transparencies. This, in turn, will lower hypolimnetic temperatures and thereby reduce the oxygen deficit (theoretically via reduced bacterial activity).

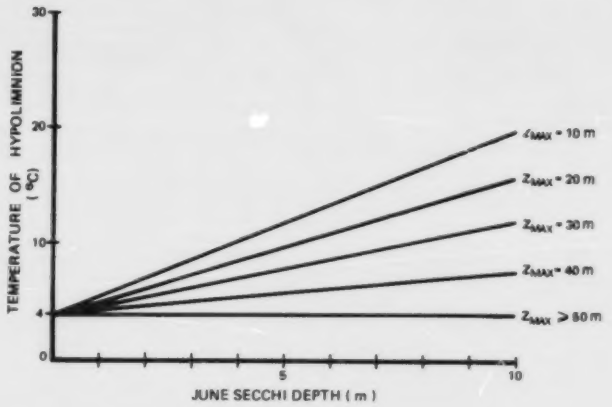


Figure 5.10 Temperature of hypolimnion as a function of Secchi depth and maximum depth (Z_{MAX})

The mean thickness of the hypolimnion (Z_H) is assumed to operate essentially in reverse to the hypolimnetic temperature, that is, the thickness increases with maximum depth and is inversely proportional to Secchi depth at transparencies less than 5 m (Figure 5.11). This relationship tends to counteract the hypolimnetic temperature function discussed above. As transparency drops, the thickness of the hypolimnion increases, resulting in a greater AHOD.

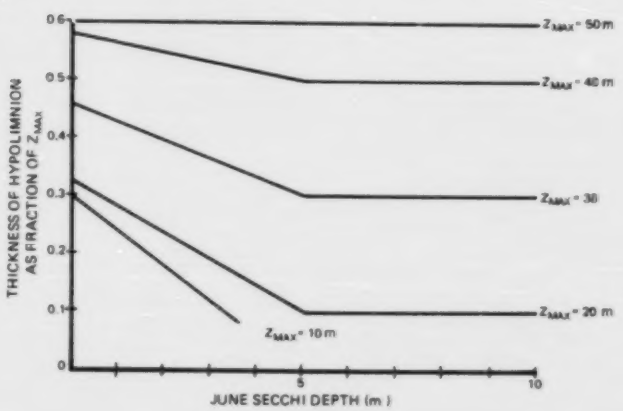


Figure 5.11 Mean thickness of hypolimnion as a function of Secchi depth and maximum depth (Z_{MAX})

A minimum hypolimnetic thickness of 1 m is assumed, to avoid negative values in the ln (Z_H) term of Equation 5.15. This assumption only becomes relevant for highly transparent, shallow lakes where Z_{MAX} is less than 10 m and SECCHI is greater than 5 m.

The net effect of the relationships presented in Figures 5.10 and 5.11 on AHOD is shown in Figure 5.12, for lakes of various depths. At maximum depths, the net contribution of the hypolimnion temperature and thickness terms of the AHOD decreases as transparency decreases.

Hypolimnetic oxygen depletion generally is accelerated by nutrient enrichment. For this acceleration to take place (Figure 5.12) in the submodel, all of the increase in AHOD must originate from the phosphorus retention term. AHOD predictions, using both methods, are compared in Appendix B.

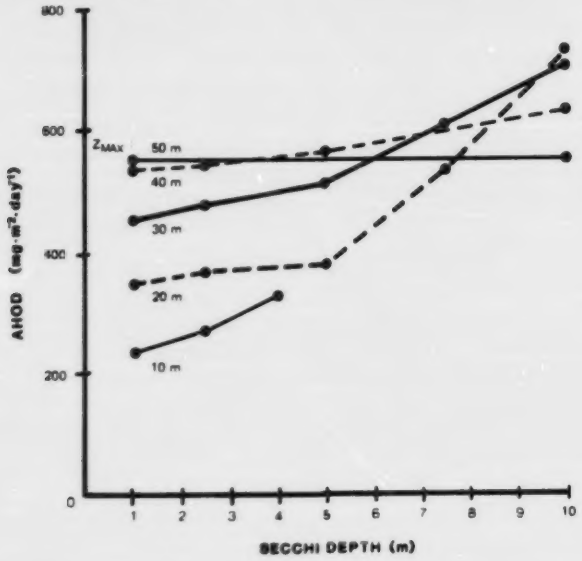


Figure 5.12 Net effect of changed transparency on the AHOD

Dissolved oxygen concentrations at spring and fall turnover are set by the user and typically vary from 10 to 12 $mg \cdot L^{-1}$. The two estimates of AHOD (direct and indirect) are converted from oxygen as $mg \cdot m^{-2} \cdot day^{-1}$ to $mg \cdot L^{-1} \cdot month^{-1}$, and multiplied by the length of the summer stratified season (generally 5.5 months) to yield the expected decreases in oxygen concentration over the summer period. Subtracting these monthly expected decreases from the input spring overturn concentration yields the summer minimum hypolimnetic oxygen concentration.

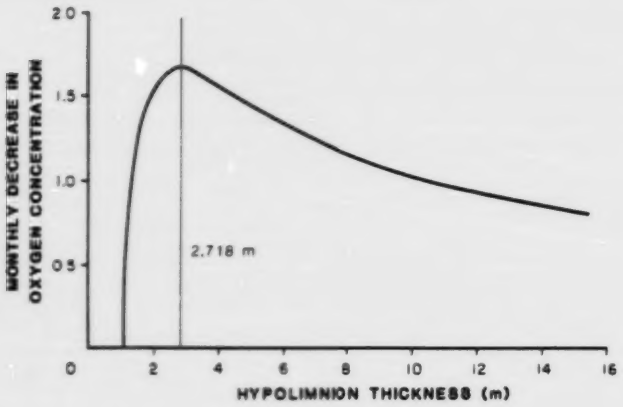


Figure 5.13 Effect of hypolimnion thickness on monthly decrease in oxygen concentration (independent of hypolimnetic temperature and phosphorus retention)

Since the AHOD calculated from Equation 5.15 is divided by the hypolimnion thickness (Z_H) to determine the volumetric oxygen depletion rate, the oxygen decrease is proportional to $\ln Z_H/Z_H$. The consequences of this proportionality are shown in Figure 5.13.

The maximum monthly decrease in oxygen concentration (other factors being equal) occurs at a hypolimnion thickness of 2.718 m. Where the hypolimnion thickness is less than 2.718 m, the predicted summer oxygen concentration drops off sharply. This reduction is a consequence of the regression Equation 5.15.

The minimum winter oxygen concentration is calculated from the winter oxygen deficit (WOD), which is estimated by the multiple regression of Welch et al (1976):

$$WOD = 315.7 + 20.8(\bar{Z}) - 38.2(SECCHI) - 1.5(\rho) - 1.8(\bar{Z}_{MAX}) \quad (5.18)$$

where WOD = winter oxygen deficit ($mg \cdot m^{-2} \cdot day^{-1}$ for entire lake);
$\bar{Z}$ = mean depth of lake (m);
SECCHI = mean summer Secchi depth (m)[4];
ρ = flushing rate (yr^{-1}); and
Z_{MAX} = maximum depth of lake (m).

The areal units of WOD apply to the whole lake, whereas those for AHOD apply only to the hypolimnion. As there is no appreciable stratification, the winter dissolved oxygen concentrations apply to the whole lake volume.

5.13 BACTERIA

The proportion of water samples in a public swimming area containing detectable levels of *Pseudomonas aeruginosa* which causes *otitis externa*, an infection of the human ear, was found (Burger 1983) to be affected by:

(a) the distance to the nearest septic tank, drainage ditch, lagoon, or other source of the bacteria,
(b) the density of swimmers using the beach, and
(c) the temperature of the water.

[4] Welch et al (1976) do not specify which season's Secchi depths should be used in the equation.

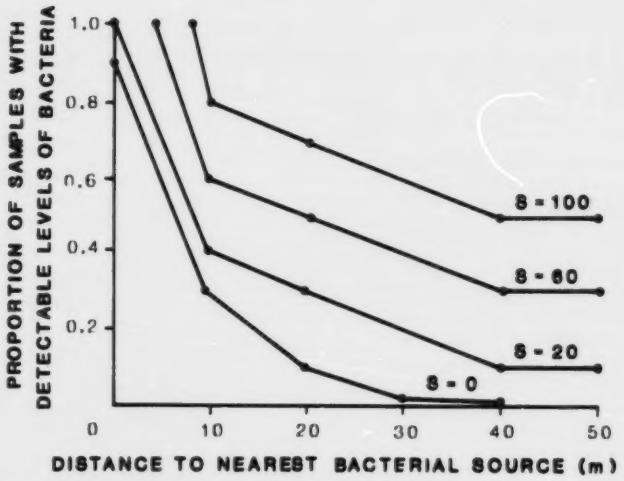


Figure 5.14 Proportion of water samples with detectable *Pseudomonas aeruginosa* (S = number of swimmers/100 m of beach)

The hypothetical curves in Figure 5.14, based on consultation with the Microbiology Component during the model-building workshops, are used to calculate the proportion of samples containing bacteria on the day of the month with maximum swimmers. To represent the increased growth of bacteria at higher temperatures, this calculated value is raised by five percent for each degree above 20°C. Referring to Figure 5.16, for example, with 60 swimmers per 100 m and no source of bacteria within 50 m, the predicted proportion of samples with detectable levels of *P. aeruginosa* is 0.3 or 30%. For a water temperature of 24°C the proportion would be raised by 20% (4 × 5%). Therefore, the proportion of positive samples would be 0.3 × 1.2 = 0.36.

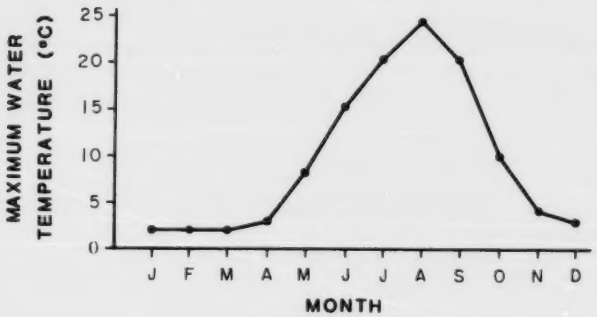


Figure 5.15 Maximum mean daily water temperatures at beach

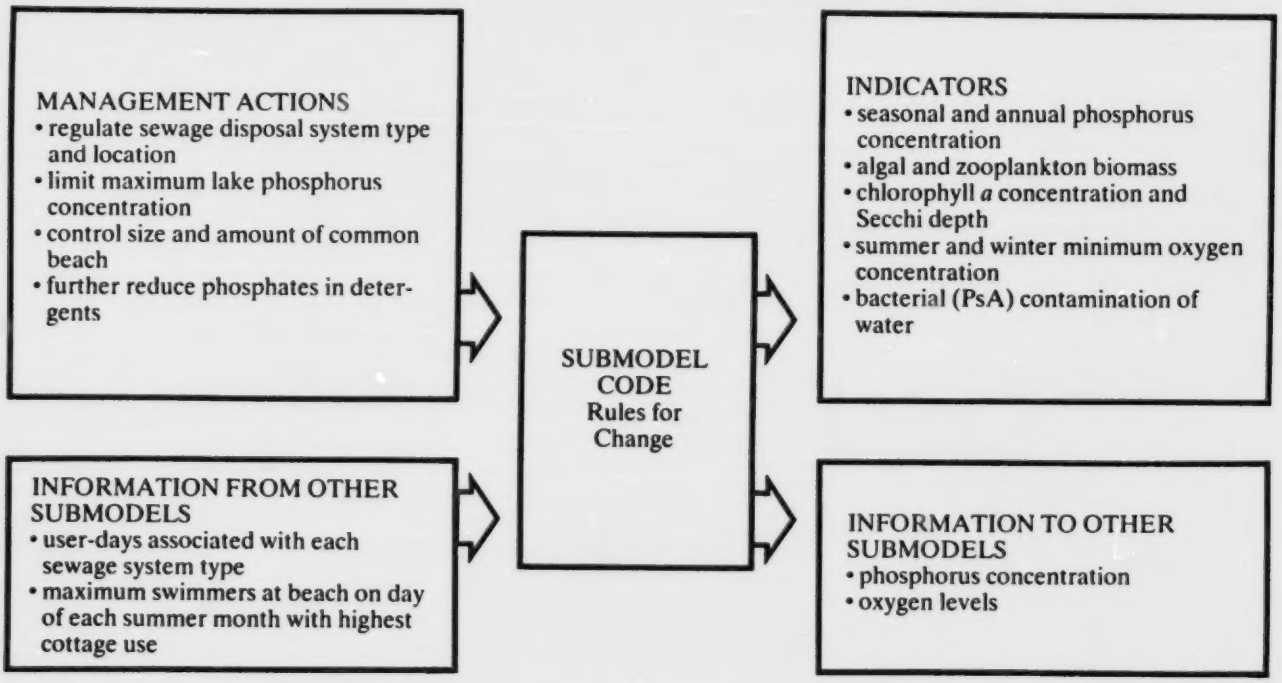
If the temperature drops below 10°C, the proportion of samples with bacteria is set to zero. Figure 5.15 is used to generate maximum mean daily water temperatures at the beach.

The prediction of the actual percentage of swimmers with ear infections was too uncertain to be included in the model. This uncertainty is primarily due to the difficulty of attributing recorded ear infections to bacteria in the lake where a swimmer is interviewed. Swimmers may have contracted the infection at other lakes or from a non-aquatic vector (Burger, pers. comm. 1981).

If a common beach is proposed, the user should specify the beach length which will then be associated with the development. If there is no public beach, an input of zero beach length initiates an algorithm to calculate frequency of occurrence of the bacteria along the shoreline, i.e. conditions likely to be encountered by cottagers swimming in the lake near their cottages (section 4.6).

5.14 SUMMARY

The Water Quality Submodel provides predictions of the impact of cottage development on the lake trophic status and microbiology. The submodel simulates the impact of existing and proposed cottages and can be altered in accordance with user-specified management actions. Information computed in the Land Use Submodel and relevant input data are used in the Water Quality Submodel to generate both the water quality indicators and specific information required by the Fisheries Submodel. The following input-output box diagram summarizes these submodel elements.


MANAGEMENT ACTIONS
• regulate sewage disposal system type and location
• limit maximum lake phosphorus concentration
• control size and amount of common beach
• further reduce phosphates in detergents
INFORMATION FROM OTHER SUBMODELS
• user-days associated with each sewage system type
• maximum swimmers at beach on day of each summer month with highest cottage use
SUBMODEL CODE
Rules for Change
INDICATORS
• seasonal and annual phosphorus concentration
• algal and zooplankton biomass
• chlorophyll *a* concentration and Secchi depth
• summer and winter minimum oxygen concentration
• bacterial (PsA) contamination of water
INFORMATION TO OTHER SUBMODELS
• phosphorus concentration
• oxygen levels

6. FISHERIES SUBMODEL

Fisheries Component scientists focussed their research on the relationship of angling activity to the depletion of the lake trout population in Study Area lakes (McCombie 1983). The researchers developed a set of linked equations which in total are able to produce predictions of:

a) the sport fish production capacity of a lake;
b) the amount of fishing effort by cottagers;
c) the amount of fishing effort by non-cottagers;
d) the seasonal (summer-winter) distribution of fishing effort;
e) the harvest resulting from the estimated total fishing effort; and
f) the relationship of the estimated catch to the amount that can be harvested indefinitely (surplus production) without adversely affecting the population.

The Fisheries Submodel developed for the OLCSM incorporates most of the Fisheries Component's research results. However, during the submodel development the boundaries were broadened to include the following:

a) a representative warm water species, the smallmouth bass;
b) the effect of water quality changes on fish production and survival; and
c) a linkage between the Land Use Component's prediction of cottage use and the calculated fishing effort.

The smallmouth bass was chosen because:

a) it does not compete for the same resource base as lake trout and should therefore be sensitive to different impacts of cottage development;
b) it is important to the recreational fisheries of Ontario Precambrian Shield lakes which include warm water lakes; and
c) data on smallmouth bass are available in the Fisheries Component data base and in the scientific literature.

A realistic measure of the cottaging impact is impossible without including the water quality effects on fish, e.g. reduction in hypolimnetic oxygen concentrations. For this reason, an oxygen linkage was created between the Water Quality and Fisheries submodels.

Finally, an additional equation for estimating fishing effort was included. This equation uses Land Use Component cottage-use data rather than the number of cottages. The advantage of this approach is that the fishing effort estimate reflects the lake-to-lake variations in cottage use resulting from differences in the type of cottage access. Presentation of both methods indicates the underlying factors involved and bares the strengths and weaknesses of each method.

6.1 PREDICTING FISH PRODUCTION

The core of the Fisheries Component study is the morphoedaphic index (MEI) developed by Ryder (1965). The index is calculated by dividing the total dissolved solids (TDS) measurement by the lake mean depth. It has been used as a rapid method of calculating potential fish yield for inland lakes in north temperate (Ryder 1982), subtropical and tropical (Schlesinger and Regier 1982) zones of the world. When Ryder regressed fish yield on the MEI the following predictive equation emerged:

$$MSY_c = 1.30 * MEI^{0.447} \qquad (6.1)$$

where MSY_c = maximum sustained yield of the lake's sport fish community ($kg \cdot ha^{-1} \cdot yr^{-1}$); and
MEI = morphoedaphic index (TDS/mean lake depth).

The assumption inherent in using the MEI is that the fish population is in equilibrium with both the biological environment and fishing pressure. These assumptions would be violated if fishing pressure were to drive fish populations to levels far below their equilibria or if, alternatively, acid rain were to raise total dissolved solids but directly deplete fish stocks. Therefore, in this submodel MEI is used as an indicator of potential production and linked to a more dynamic representation of fish population changes.

The basic formula used is the Schaefer equation (Schaefer 1957) for surplus fish production. The equation predicts the change in fish biomass (dB) with a change in time (dt):

$$\frac{dB}{dt} = RB\left(1 - \frac{B}{K}\right) - qEB \qquad (6.2)$$

where R = intrinsic growth rate of the population, also called natural growth rate (yr^{-1});
B = biomass of the population ($kg\ wet\ weight \cdot ha^{-1} \cdot yr^{-1}$);
K = carrying capacity of the environment for the species ($kg\ wet\ weight \cdot ha^{-1} \cdot yr^{-1}$);
q = catchability coefficient (Section 6.6); and
E = fishing effort ($angler\text{-}hours \cdot ha^{-1} \cdot yr^{-1}$).

This equation assumes that the growth rate of a fish population can be represented by a logistic curve (Figure 6.1). The curve shows three stages in the maturation of a population; the lower half of the curve rises rapidly, suggesting initial growth with little competition, followed by a dampening due to competition for food and space. Finally, a flat steady state is reached at which point growth and mortality are equal. Now biomass remains constant relative to the carrying capacity (K) of the lake.

In order to obtain the net biomass, the harvest term (q * E * B) is subtracted from the yield estimate (Equation 6.2). Harvest is estimated from the fishing effort and the proportion of the biomass caught in one hour of angling effort. The uncertainties associated with the determination of the latter (q) are discussed in Section 6.6. The effects of cottage development on lake trout and smallmouth bass are described as the changes in the values of R, K and E.

The Fisheries Submodel flow chart (Figure 6.2) indicates the calculations that are performed and their sequencing in the submodel. Provision has been made in the submodel for future inclusion of the linkage between changes in the littoral zone and smallmouth bass carrying capacity.

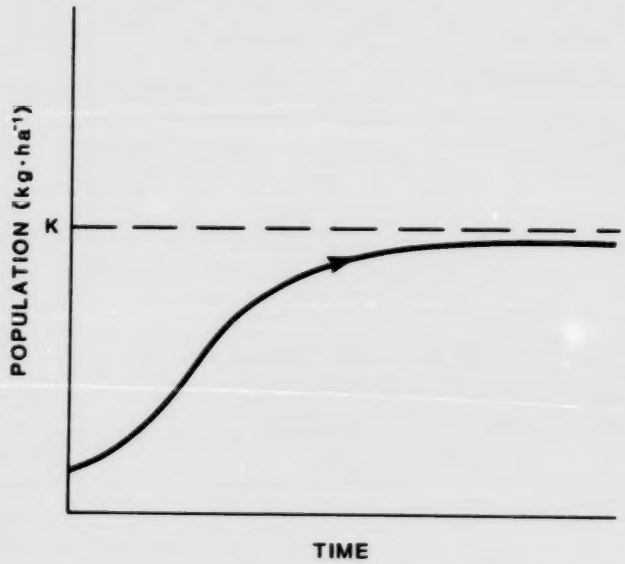


Figure 6.1 The logistic growth curve where K equals the population carrying capacity

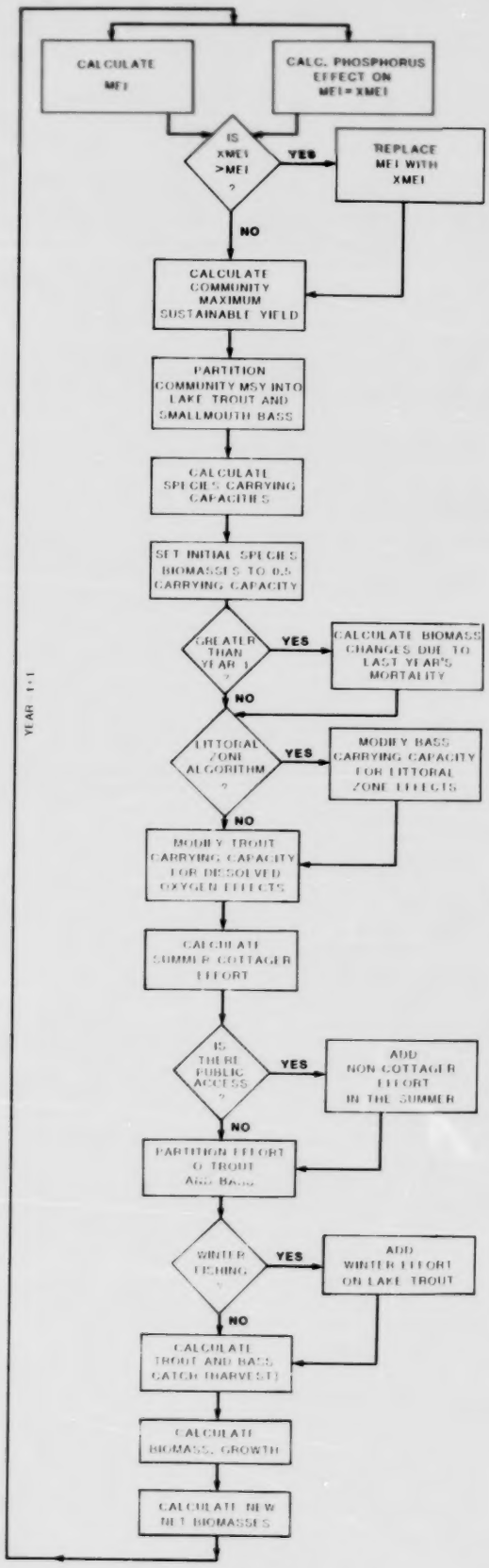


Figure 6.2 Fisheries Submodel flow chart

6.2 POPULATION GROWTH

It is assumed that the predicted yield from the MEI is equal to the maximum sustainable yield (MSY) (McCombie 1983). The biomass that yields MSY_c is assumed to be K/2 or one-half the environmental carrying capacity. If B is defined as the biomass at MSY_c:

$$\frac{K}{2} = B \text{ at } MSY_c \tag{6.3}$$

and K/2 is substituted in Equation 6.2, then:

$$\frac{dB}{dt} = \frac{RK}{4} - qEB \tag{6.4}$$

At equilibrium dB/dt = 0. Therefore:

$$\frac{RK}{4} = FB \text{ at } MSY_c \tag{6.5}$$

where F = qE, the proportion of the fish biomass harvested, i.e. the instantaneous harvest rate.

At equilibrium, the total annual survival rate of a population can be estimated by (Ricker 1975):

$$e^{-Z} = \frac{MA}{1 + MA} \tag{6.6}$$

where e^{-Z} = total annual survival rate;
Z = the instantaneous total mortality rate (natural plus harvest);
MA = mean age of the catch minus the youngest age at which fish are caught; and
e = 2.718, the base of the natural logarithm.

Given an estimate of the instantaneous natural mortality rate (M), the instantaneous harvest rate (fishing mortality) is:

$$F = Z - M. \tag{6.7}$$

Combining B = K/2 and $MSY_c = FB$:

$$K = \frac{2 * MSY_c}{F} \tag{6.8}$$

and because $MSY_c = RK/4$ (the growth element in Equation 6.4) the natural growth rate R becomes:

$$R = \frac{4 * MSY_c}{K} \tag{6.9}$$

6.2.1 LAKE TROUT

The data in Martin and Fry (1973) were used to derive parameter values for lake trout population growth:

a) natural mortality (M) is 0.25 per year; and
b) the mean age of lake trout caught is 7 years and only fish 5 years and older are caught; therefore, MA = 7-5 = 2 years.

Therefore, from Equation 6.6, Z = 0.405 and from Equation 6.7, F = 0.16. The MSY calculated using MEI is for the entire sport fish community. Fisheries Component data (McCombie 1983) suggested that in absolute terms about 40% of this MSY would be in lake trout. Therefore, substituting 0.40 into Equation 6.9:

$$TR = \frac{4 * (0.4\ MSY_c)}{5 * MSY_c} = 0.32\ year^{-1} \tag{6.10}$$

and by rearranging Equation 6.9:

$$TK = \frac{4 * (0.4\ MSY_c)}{0.32\ year^{-1}} = 5 * MSY_c \tag{6.11}$$

where TK = trout carrying capacity; and
TR = natural growth rate of trout population.

As the MSY_c is for a fish community, a method was sought for more accurately apportioning a fraction of the MSY_c to lake trout. It was decided that the more than three decades of creel census observations on Lake Opeongo (Martin and Fry 1973) would be used as a guide for partitioning the MSY_c. For Lake Opeongo, the MEI and MSY_c are 1.57 $mg \cdot L^{-1} \cdot m^{-1}$ and 1.72 $kg \cdot ha^{-1} \cdot yr^{-1}$, respectively (MNR 1982b, McCombie 1983). As the yield has changed little in the past 15 years, one can assume that it approximates MSY_c. The lake trout yield from Lake Opeongo is 0.4 $kg \cdot ha^{-1} \cdot yr^{-1}$, therefore:

$$TMSYP = (0.4/1.72)MSY_c = 0.23MSY_c \tag{6.12}$$

where TMSYP = the proportion of the MSY_c apportioned to lake trout.

This value ($0.23MSY_c$) has also been interpreted as the optimum sustained yield of lake trout for lakes in the Study Area.

6.2.2 SMALLMOUTH BASS

The data used to derive parameters of population growth for smallmouth bass came from various sources. The Ministry of Natural Resources (Shuter, pers. comm. 1981) provided most of the details of smallmouth bass biology needed to estimate BR and BK.

The fecundity of smallmouth bass is approximately nine times that of lake trout and smallmouth bass mature at a much younger age than lake trout (Scott and Crossman 1973). It was therefore hypothesized that the natural growth rate for smallmouth bass (BR) is higher than for lake trout. BR was set at 0.5 $year^{-1}$. Based on a Strategic Plan for Ontario Fisheries (SPOF) report (MNR 1982b), 50% of the MSY_c was assigned to smallmouth bass. Therefore, by rearranging Equation 6.9:

$$BK = \frac{4 * (0.5\ MSY_c)}{0.5\ year^{-1}} = 4 * MSY_c \tag{6.13}$$

6.3 PHOSPHORUS ENRICHMENT AND THE MORPHOEDAPHIC INDEX

Phosphorus enrichment has been identified not only as a root cause of lake water quality and fish habitat degradation but, during the early stages of enrichment, as a contributor to increased fish production through an enhanced food resource for predatory fish (Oglesby 1977b, Hanson and Legget 1982). Although there are no data specific to lake trout or smallmouth bass, the assumption is that they, being predatory species, are affected by this stimulus.

The fish food is not phosphorus but the edible zooplankton which, in turn, depends on phytoplankton as a food base. Phytoplankton consist of the edible algae and the non-edible blue-green algae. The ratio of nitrogen to phosphorus determines the amount of blue-green algae produced (section 5.10). When the N:P atomic ratio is < 14:1 and the base P concentration is ≥ 10 $\mu g \cdot L^{-1}$, less

phosphorus will be converted into usable fish food, thereby reducing the beneficial effect of enrichment. The nitrogen balance equation (Teleki and ESSA 1982) was included in the model to provide an estimate of the N:P atomic ratio. This permits the downward adjustment of the usable phosphorus value when the N:P ratio drops below 14:1 and the base P concentration rises above 10 $\mu g \cdot L^{-1}$. Although no lake in the Study Area has an N:P atomic ratio less than 14:1, it is important to account for this limnological relationship. In the present version of the model, the ratio is provided as an indicator and is not linked to the Fisheries Submodel because of the decision to calculate fish production from its relationship with lake nutrients (P and MEI) rather than from the linkage of P-plankton-fish production. Total nitrogen is given a mean default value of 664 $\mu g \cdot L^{-1}$.

At the same time that the "P-stimulated" total fish carrying capacity is rising, the habitat for selected sport fish, such as lake trout, is being stressed. For salmonids, in general, there is a fine line between the beneficial effect of enrichment and the negative effect of habitat degradation.

In the model, the positive effect of nutrient enrichment (phosphorus) is added to the existing MEI formulation in terms of a direct change in the MEI. The negative effect is applied by reducing the lake trout carrying capacity as a result of lowered hypolimnetic oxygen concentrations.

Data from 26 lakes (McCombie, pers. comm. 1982) were used to derive a relationship between phosphorus and the MEI.

$$XMEI = 178{,}595.59 * (YCPLK/1000)^{2.3551} \qquad (6.14)$$

where XMEI = the modified morphoedaphic index ($mg \cdot L^{-1} \cdot m^{-1}$);
YCPLK = the mean phosphorous concentration during the ice-free period ($\mu g \cdot L^{-1}$); and
n = 26
p = <0.001
r^2 = 0.79

As this regression equation proved the least accurate for small phosphorus values (actually depressing the modified MEI below the standard MEI), the submodel was redesigned so that XMEI would only be used if it was larger than the MEI. As the standard MEI is virtually a constant, the XMEI comes into use only when the phosphorus concentrations begin to rise.

6.4 DISSOLVED OXYGEN LEVELS AND LAKE TROUT

The growth and production of the lake biota is stimulated by nutrient enrichment of the lake, which is followed by increased oxygen consumption as the aquatic organisms die and decompose. Changes in dissolved oxygen (DO) levels can be linked to enrichment. During the submodel development, DO concentrations in lake hypolimnia were identified as being vital to the survival of lake trout, as they spend their entire lives in this region of the lake and must have well-oxygenated water. Smallmouth bass stay above the hypolimnion most of the time and are not affected until highly eutrophic conditions occur.

Generally speaking, lake trout are not affected by DO levels above 5 $mg \cdot L^{-1}$. At 2 $mg \cdot L^{-1}$ no lake trout can survive. The relationship over the range from 2 to 5 $mg \cdot L^{-1}$ is interpreted as a straight line (Figure 6.3).

Because no method is available for predicting hypolimnetic oxygen levels by depth stratum (hypolimnetic oxygen usually drops with depth), a conservative approach to oxygen forecasting was devised. The minimum oxygen concentration during the summer was used for all fish survival calculations. As changes in hypolimnetic DO are related directly to the trout carrying capacity (K), when DO drops below 5 $mg \cdot L^{-1}$ a progressively smaller portion of the initial carrying capacity (K) remains (Figure 6.3).

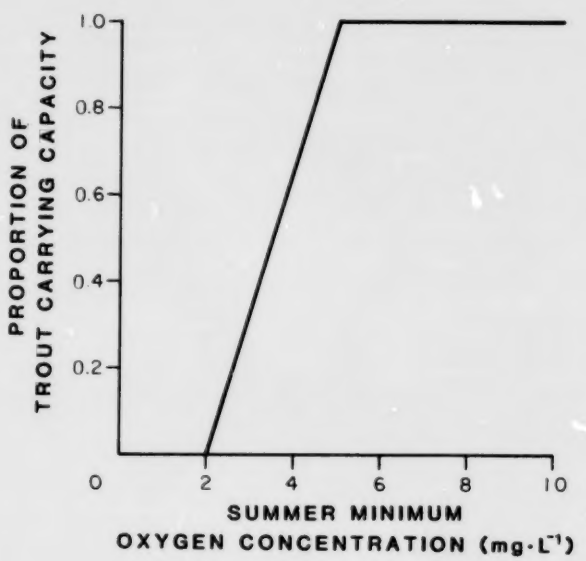


Figure 6.3 Effect of dissolved oxygen level in hypolimnion during the summer on lake trout carrying capacity

The mathematical calculation is simply:

TKO = TK * Proportion of initial TK remaining (from Figure 6.3)

where TK = the initial carrying capacity for lake trout derived from the morphoedaphic index; and
TKO = the potential lake trout K with the dissolved oxygen effect subtracted.

This is a powerful relationship since salmonid carrying capacity (K) and biomass are directly reduced once hypolimnetic oxygen drops below a mean of 5.0 $mg \cdot L^{-1}$.

The XMEI and oxygen effect have been programmed into the model so they always work together. If the nutrient enrichment causes depressed oxygen levels in the lake, then the lake trout carrying capacity is reduced proportionally at a rate shown in Figure 6.3. The model makes these adjustments during each simulation time-step.

As there are other stresses, particularly over-fishing, influencing lake trout production, being able to separate the enrichment effects (both positive and negative) from the fishing and other stresses, helps to identify the relative contribution of each stress to the changing fish production level.

6.5 FISHING EFFORT

A major effect of increased cottage development on fish populations is a rise in the amount of fishing effort. The Fisheries Component scientists addressed this problem by examining the following relationships:

a) cottager effort in summer as a function of the number of cottages and the lake surface area;
b) non-cottager effort in the summer as a function of summer cottager effort (provided that public access exists); and
c) total winter fishing effort as a function of total summer fishing effort.

6.5.1 COTTAGER FISHING EFFORT IN SUMMER

Summer fishing effort by cottagers was derived, initially, with an equation developed by McCombie (1983):

$$E_c = [(e^{1.576-0.000148 \cdot A}) \cdot N] / A \qquad (6.15)$$

where E_c = cottager fishing effort in summer fishing season (angler-hrs · ha^{-1});
A = lake surface area (ha); and
N = number of cottages.

This equation is responsive to variations in fishing effort resulting from differences in lake surface area.

An alternate formulation was prepared using several Study Area and lake-specific constants in addition to a cottage use variable.

The advantage of the following equation is that it takes into account differences in cottage use from lake to lake, resulting from variations in the type of access, rather than assuming average cottage use on all lakes. Also, it allows the user to define the summer fishing season (which may vary locally) and to test management options by predicting angling effort under changed season lengths.

$$ECS = \frac{FUSES \cdot PFISH \cdot ANGLER \cdot HOURS \cdot PTIME}{AREAL} \qquad (6.16)$$

where ECS = cottager fishing effort in summer (angler-hours · ha^{-1});
FUSES = number of cottage-days during summer fishing period (May-September);
PFISH = proportion of cottages with occupants who fish in summer (= 0.5);
ANGLER = number of people per fishing trip (= 2);
HOURS = number of hours per fishing trip (= 2);
PTIME = proportion of total summer cottage-days spent fishing (= 0.33); and
AREAL = surface area of the lake (ha).

At present, both equations are programmed in the model but they operate independently. Further work is required to combine into one equation the strengths of the two methods of predicting summer cottager fishing effort.

6.5.2 NON-COTTAGER FISHING EFFORT IN SUMMER

McCombie (1983) regressed non-cottager effort in the summer on cottager effort in summer, as the creel census data indicated a relationship between the number of cottager and non-cottager anglers on the Fisheries Component study lakes. This regression equation is used in the Fisheries Submodel:

$$ENS = 0.518 \cdot ACCESS \cdot ECS^{1.2004} \qquad (6.17)$$

where ENS = non-cottager effort in the summer (angler-hours · ha^{-1}); and
ACCESS = a code to indicate whether there is a public access point on the lake. If ACCESS = 0, there is no public access. If ACCESS = 1, there is a maintained public access point and therefore non-cottager fishing.

6.5.3 APPORTIONING FISHING EFFORT

The proportion of fishing effort expended on the lake trout and smallmouth bass was initially divided equally between the two species. However, it remains a user-defined parameter. For example, field biologists may have first-hand knowledge of the effort allocation, in which case the new proportions would replace the old. Provision for a proportion of effort for other fish species has been made, as in some cases additional species make up a significant part of total fishing activity. The apportioning of effort is achieved with the following equations:

$$BEFF = 1.0 - TEFF - POEFF \qquad (6.18)$$

where BEFF = the proportion of the estimated fishing effort (angler-hrs · ha^{-1}) going to smallmouth bass;
TEFF = the proportion of the fishing effort going to lake trout, with data provided by the user; and
POEFF = the proportion of the total estimated fishing effort going to other species, with data provided by user.

6.5.4 WINTER FISHING EFFORT

McCombie (1983) hypothesized that, when selecting a winter fishing site, anglers relied on the fishing reputation of a lake. Waters with good summer lake trout fishing received higher winter fishing effort than lakes with a poor summer lake trout catch. McCombie developed the following regression equation for predicting winter lake trout fishing effort:

$$EFFW = 0.811 \cdot WINTER\ (EFFS)^{0.962} \qquad (6.19)$$

where EFFW = winter fishing effort for lake trout (angler-hours · ha^{-1});
EFFS = summer fishing effort by cottagers and non-cottagers (angler-hours · ha^{-1}); and

WINTER = a switch to mimic presence or absence of winter fishing (not part of McCombie's equation). If WINTER = 0, there is no winter fishing. If WINTER = 1, there is winter fishing.

Data collected by both the Fisheries and Land Use Components indicate that winter anglers are largely non-cottagers. The Land Use Component Survey of Lakeshore Residents revealed that although 49% of the cottages have occupants who fish in summer, only 5% of the cottages have occupants who fish in winter (MOH 1979). This is important when evaluating management options, as reducing the number of cottages will have only a slight effect on winter fishing effort.

6.5.5 FISHING EFFORT CONTROLS: SHORTENING SEASONS

When faced with dwindling fish stocks and a growing angler population, managers sometimes shorten the fishing season. This has the effect of reducing the total harvest, thus allowing more fish to mature, reproduce and replenish the population. In the model, the user can 'set' the fishing season by giving new numerical values to the following variables:

ISS — first month of summer fishing season;
ISF — last month of summer fishing season;
IWS — first month of winter fishing season;
IWF — last month of winter fishing season; and
ISEAS — a switch which turns the entire summer fishing season on (ISEAS = 1) or off (ISEAS = 0).

For example, ISS = 7 and ISF = 8, sets the summer fishing season to two months, July and August; or IWS = 1 and IWF = 3 sets the winter season to January through March.

6.6 CATCHABILITY COEFFICIENT

The catchability coefficient "q" (Equation 6.20) is the proportion of the fish stock caught per unit of fishing effort, e.g. boat-day, rod-hour or angler-hour. The literature is replete with analyses (Peterman and Steer 1981, Paloheimo 1980, Holling 1959) suggesting how the q is related to fish abundance, how it should be derived and ultimately how elusive a parameter (or variable) it can be. Using Holling's work (1959), Peterman and Steer (1981) described the relationship of q to fish abundance and suggested that an exponential decay curve (Figure 6.4, A) was the most appropriate for fish harvest situations — as the fish population grows, q drops.

What clouds this relationship is the influence of angler skill and gear efficiency on q. Unfortunately, there are no functional relationships that can be applied to correct for this factor, so the best available solution is to make q as lake-specific as possible.

6.6.1 LAKE TROUT q

The steps leading to a lake-specific lake trout q began with a conversion of Paloheimo's (1980) q for Lake Opeongo lake trout from 0.0262 per hundred boat-hours to 0.000131 per angler-hour. In applying this q, few if any trout populations were ever stressed, even with unreasonably high levels of fishing effort.

Since q is influenced by fish abundance which, in turn, is a function of the trophic status of the lake, and since abundance is also related to fishing pressure, a forward stepwise regression analysis was performed. This was done to determine the combination of fishing effort, MEI and/or biomass which was the most useful in predicting q.

The q values for the regression were derived from a reformulation of the harvest (Y) part of the Schaefer equation (Equation 6.4). If $Y = qEB$, then $q = Y/(E \times B)$. The lake trout summer effort and harvest data were obtained from the Fisheries Component Creel Census. The predicted lake trout biomass was used because there were no measured values available. The biomass prediction represents an estimate of biomass at the maximum sustained yield.

The analysis, using Fisheries Component lakes, revealed that, for lake trout, fishing effort and MEI were the best predictors of q and that these two variables did not exhibit multicollinearity. The intention was that this formulation be used in the model and the method of estimating q re-evaluated following the collection of new q related fisheries data. The resulting equation, using the SAS (1979) STEPWISE procedure was:

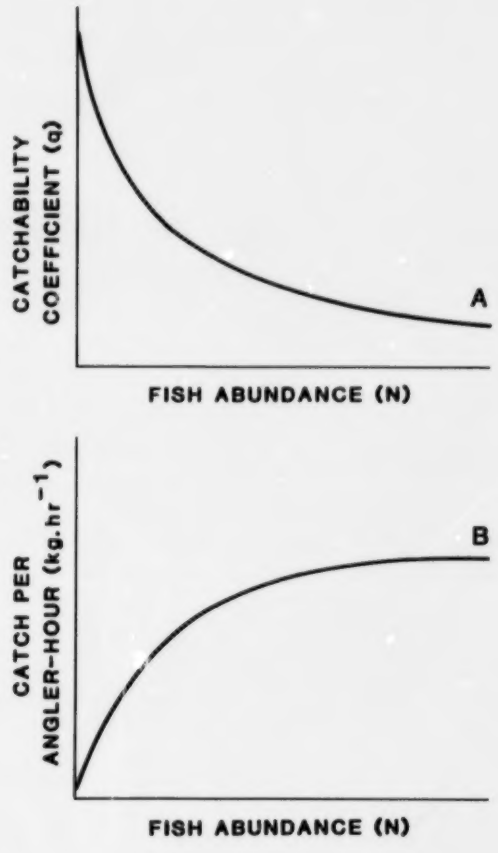


Figure 6.4 Most likely response of the catchability coefficient (A) and catch (B) to changes in fish abundance, e.g. biomass (from Peterman and Steer 1981 after Holling 1959)

$$q_{LT} = 0.642 - 0.0365\ (\ln MEI) + .0011\ Effort_{LT} \qquad (6.20)$$

$n = 12$

$F_{0.023} = 6.32;\ 2, 8\ d.f.$[1]

$r^2 = 0.61$

where

q_{LT} = catchability coefficient for lake trout;

$Effort_{LT}$ = total summer effort for lake trout; and

ln = natural logarithm

The fact that effort is implicit in q strengthens the argument that it be applied to calculate lake-specific q values.

Both variables reflect the response curve established by Peterman and Steer (1981) in that, as effort rises, catch increases. The resulting reduction in fish abundance causes q to rise. Similarly, as MEI rises fish abundance tends to rise, i.e. MEI is indirectly related to q (correlation coefficient = −0.64).

[1] "F" statistic is the ratio of explained variance to unexplained variance. The larger the "F" statistic, the smaller is the unexplained variance portion of the statistic in relation to the explained portion.

The q values for summer and winter fishing are assumed to be equal as no data are available substantiating a consistent difference in the q between fishing seasons (McCombie 1983).

6.6.2 SMALLMOUTH BASS q

Since Lake Opeongo data did not include the q for smallmouth bass, a different approach was taken. The basic assumptions used in calculating smallmouth bass q were:

a) The natural mortality rate for smallmouth bass is 0.25 per year, minimum estimate (Shuter, pers. comm. 1981)

b) Approximately 50% of the MSY_c estimated harvest is smallmouth bass (MNR 1982)

c) The fecundity of smallmouth bass is about nine times that for lake trout. Also, the age at first maturity for smallmouth bass is less than that for lake trout (Scott and Crossman 1973). Therefore, it was hypothesized that BR was about 70% higher than TR. As a trial value, BR was set at 0.54 yr^{-1} ($1.7 * TR = 0.54\ yr^{-1}$)

d) Using equation 6.4 and substituting for BR: $BK = 3.7\ MSY_c$

e) Catch per unit of effort (CPE) for lake trout is 3.1 times that for smallmouth bass. From the Fisheries Component study data (McCombie, pers. comm. 1981) on 12 lakes, $CPE_{SMB} = 12.5$ gm · angler-hour^{-1} and $CPE_{LT} = 38.8$ gm · angler-hour^{-1}.

Since: $CPE = qB$

and the average biomass of lake trout is approximately six times the average biomass of smallmouth bass, then:

$$\frac{q_{LT}}{q_{SMB}} = \frac{38.8}{12.5} * \frac{B_{SMB}}{6 * B_{SMB}}$$

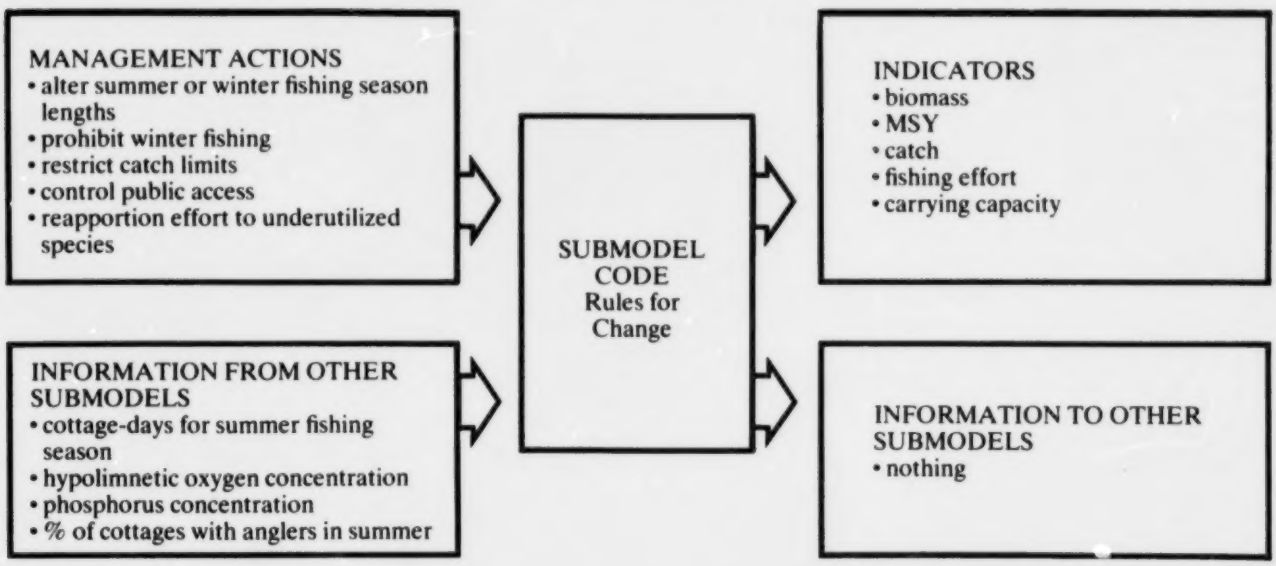
where q_{LT} = as above.

Solving for q_{SMB} produces the following equation:

$$q_{SMB} = \frac{q_{LT} * 6B_{SMB}}{3.1\ B_{SMB}} \qquad (6.21)$$

6.7 SUMMARY

The Fisheries Submodel provides predictions of the impact of cottage development on the sport fish population of a lake. The submodel simulates the impact of existing and proposed cottages and can be altered in accordance with user-specified management actions. Information computed in the Land Use and Water Quality submodels and relevant input data are used in the Fisheries Submodel to generate fisheries indicators. The following input-output box diagram summarizes these submodel elements.



7. WILDLIFE-HABITAT SUBMODEL

The basic underlying assumption of the Wildlife Component research is that lakeshore cottage development alters the structure and species composition of the shoreland vegetation, i.e. the wildlife habitat. The alteration of wildlife habitat, in turn, affects wildlife populations (Figure 7.1).

The Wildlife-Habitat Submodel first estimates an index of disturbance, based on the density of cottage development. This index is the basis for many of the other calculations in the submodel. A flow chart of the submodel is shown in Figure 7.2.

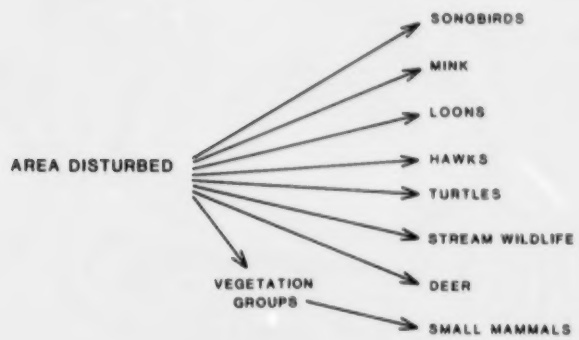


Figure 7.1 Impact of cottages on wildlife habitat for selected species, using area disturbed by development as the basis for evaluation

7.1 SPATIAL REPRESENTATION OF THE LAKESHORE AND LITTORAL ZONE

The area considered to be important to wildlife is a 50-m band of shoreland surrounding the lake. In order to relate the location of cottages to types of wildlife habitat, this strip of land is divided into segments of equal size. The user chooses a uniform segment width within the range of 50 to 200 m. The smaller segments are preferable as they best describe the amount of transition zone between developed and undeveloped sites. Each wildlife segment is classified into one of three forest cover types: coniferous, deciduous, or mixed (coniferous plus deciduous).

The lot size is the area of the lot within the 50-m strip of shoreland, i.e. the width of the registered lot multiplied by 50 m, rather than the area of the registered lot.

The littoral zone is divided into a linear grid of segments of the same width as the segments on the adjacent lakeshore. The distance they extend into the lake is not explicitly defined. The littoral zone segments are classified by type: weedy (includes litter) or rocky (includes sand and gravel).

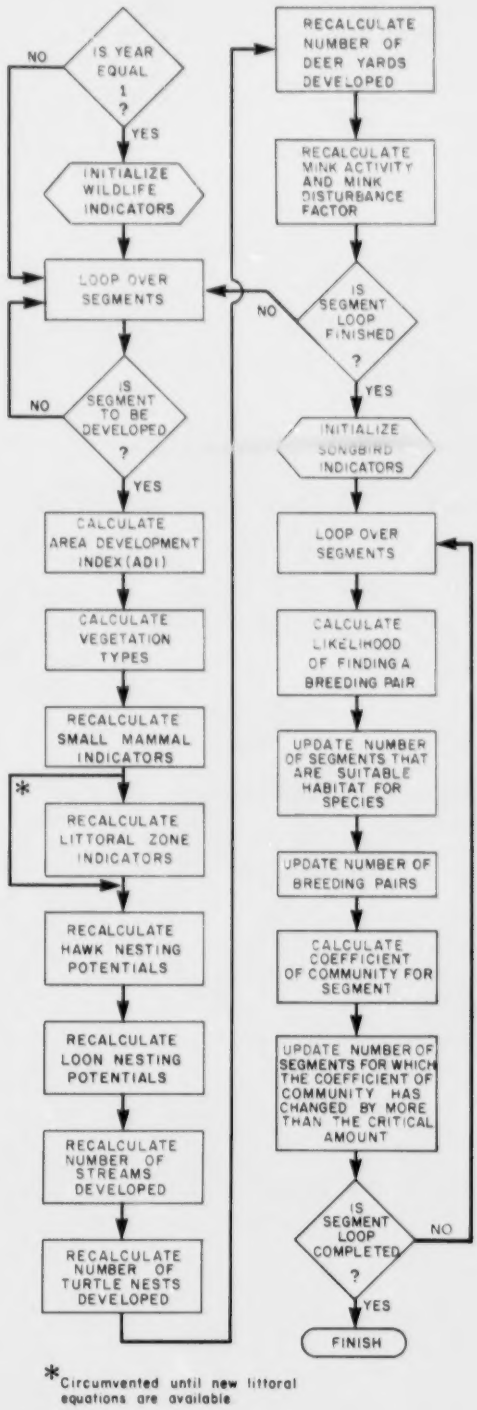

IS YEAR EQUAL 1 ?
NO
YES
INITIALIZE WILDLIFE INDICATORS
LOOP OVER SEGMENTS
IS SEGMENT TO BE DEVELOPED ?
NO
YES
CALCULATE AREA DEVELOPMENT INDEX (ADI)
CALCULATE VEGETATION TYPES
RECALCULATE SMALL MAMMAL INDICATORS
*
RECALCULATE LITTORAL ZONE INDICATORS
RECALCULATE HAWK NESTING POTENTIALS
RECALCULATE LOON NESTING POTENTIALS
RECALCULATE NUMBER OF STREAMS DEVELOPED
RECALCULATE NUMBER OF TURTLE NESTS DEVELOPED
RECALCULATE NUMBER OF DEER YARDS DEVELOPED
RECALCULATE MINK ACTIVITY AND MINK DISTURBANCE FACTOR
IS SEGMENT LOOP FINISHED ?
NO
YES
INITIALIZE SONGBIRD INDICATORS
LOOP OVER SEGMENTS
CALCULATE LIKELIHOOD OF FINDING A BREEDING PAIR
UPDATE NUMBER OF SEGMENTS THAT ARE SUITABLE HABITAT FOR SPECIES
UPDATE NUMBER OF BREEDING PAIRS
CALCULATE COEFFICIENT OF COMMUNITY FOR SEGMENT
UPDATE NUMBER OF SEGMENTS FOR WHICH THE COEFFICIENT OF COMMUNITY HAS CHANGED BY MORE THAN THE CRITICAL AMOUNT
IS SEGMENT LOOP COMPLETED ?
NO
YES
FINISH
* Circumvented until new littoral equations are available

Figure 7.2 Wildlife Submodel flow chart

7.2 HABITAT DISTURBANCE

For many wildlife species, any degree of cottage development on a lakeshore segment makes it unsuitable as wildlife habitat. This is the case for deer, turtles and animals that rely on stream habitats. For others, such as small mammals, mink, songbirds, loons and hawks, it is the degree of disturbance that is important.

The degree of disturbance was calculated directly from measurements of the proportion of the area of the Wildlife Component study plots disturbed in each of three shoreland vegetation layers (ground, shrub, and tree). These three proportions were summed to obtain an index of disturbance which has a range in value from 0.0 to 3.0, with 0.0 representing minimum disturbance and 3.0 representing maximum disturbance. When applied to a cottage lot, it is termed the Area Development Index (ADI).

$$ADI = (Ag + As + At) / AREA \qquad (7.1)$$

where
- Ag = area disturbed (ha) in the ground layer due to cottage development;
- As = area disturbed (ha) in the shrub layer due to cottage development;
- At = area disturbed (ha) in the tree layer due to cottage development; and
- AREA = area (ha) of the cottage lot (within the 50-m band).

The Wildlife Component team found that the actual area disturbed per lot was relatively uniform and independent of the size of the lot. As the lot size increased, the proportion of the lot disturbed decreased, leading to a reduction in the ADI (Figure 7.3).

In the Wildlife-Habitat Submodel, the ADI is calculated from the mean lot size per segment and is used to predict habitat disturbance for small mammals, songbirds and mink.

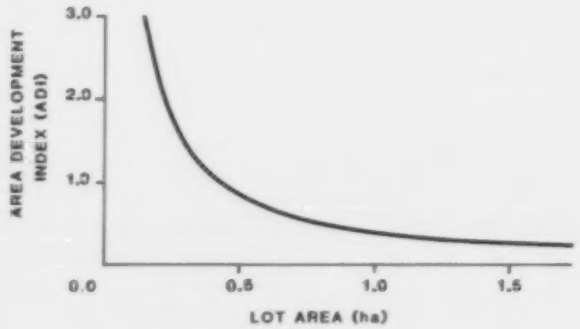


Figure 7.3 Area Development Index as a function of lot size

7.3 CAPTURE INDICES FOR SMALL MAMMALS

The Wildlife Component scientists (Racey and Euler 1982) were able to show that one could predict the change in small mammal numbers by examining changes in the amount of vegetation (single species or an assemblage of species) within each lakeshore segment.

Best fit regression equations were developed using several multivariate statistical procedures (Racey and Euler 1982), resulting in an equation which, for each major forest cover type, could best predict the relative small mammal populations. The Capture Index is an index of population size rather than absolute numbers for each species.

A statistical technique was used to select those vegetative groups which were most useful in the prediction. For example, Figure 7.4 illustrates the relationship used for estimating the density of the ground species *Clintoria borealis* (CLIN) in coniferous habitat at different levels of disturbance. Similar relationships were developed for 108 different vegetation groups occurring in the three major forest cover types (coniferous, mixed, deciduous). These relationships are internal to the submodel program.

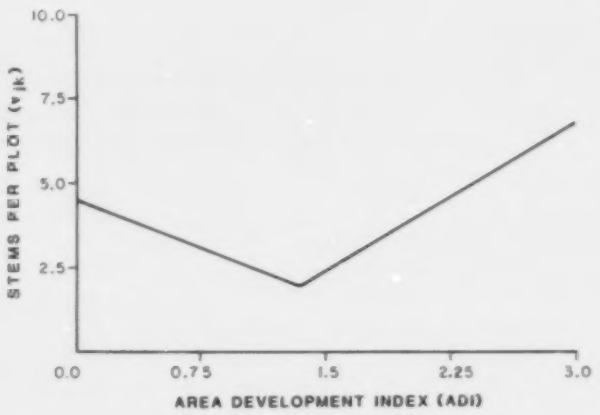


Figure 7.4 Relationship between density (stems/plot) of *Clintonia borealis* in coniferous habitat and the Area Development Index used in the submodel

The small mammal group in the Wildlife Submodel includes shrews (2 species), mice (2 species), chipmunks, squirrels and voles. The general form of the equation used in the submodel to calculate the Capture Index for each of the seven small mammal species is:

$$CI_{ij} = a_j + \sum_{k=1}^{n} b_{jk} * v_{jk} \qquad (7.2)$$

where
- CI_{ij} = Capture Index for small mammal species i in major forest cover j;
- a_j = regression equation intercept for forest cover type j (deciduous, mixed or coniferous);
- b_{jk} = regression coefficient associated with the major forest cover j and the species group k;
- v_{jk} = estimate of amount of vegetation (stems/plot) for the specific species group k within the major forest cover j; and
- n = maximum number of regression coefficients (i.e. b_{jk}) as determined by the regression analyses.

Several b and v values make up each regression equation. The predictive equation for the Capture Index of the masked shrew, *Sorex cinereus* in coniferous habitat is:

$$CI = -0.188 + 0.054(BETP) + 0.015(CLIN) \quad (7.3)$$

where BETP and CLIN are the v_{jk} vegetation values

The capture indices for small mammals on individual shoreland segments are summed to obtain a lakewide index for measuring changes in small mammal habitat.

7.4 MINK

The submodel calculates two measures of the change in mink habitat: the lakewide mink activity index and a mink disturbance index.

7.4.1 MINK ACTIVITY INDEX

The Wildlife Component scientists developed an equation that gives a numerical value to the level of mink activity along the lakeshore, based on signs of mink activity observed in the field. The mink activity index (M) was calculated for each study plot and 50 m on either side of it in the following way:

$$M = S + P + D + T \quad (7.4)$$

where S = log (no. of scats);
P = scent posts: either 1 for a minor scent post or 2 for a major scent post;
D = dens: either 2 for a possible den[1] or 5 for a confirmed den; and
T = tracks: 1 if the only sign of mink activity is a track.

In the Wildlife-Habitat Submodel, the mink activity index is calculated from its relationship with the forest cover type and ADI in each lakeshore segment (Figure 7.5). As cottage development increases, the submodel computes the change in the mink activity index from the index prior to the existing development (predevelopment).

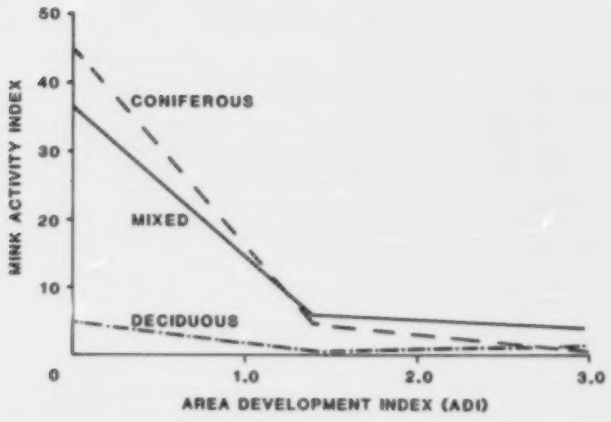


Figure 7.5 Mink activity index as a function of the Area Development Index, for three forest cover types

[1] A possible den was defined as lacking fresh scats on at least one of the shorewalking rounds while a confirmed den had fresh signs of mink activity on each round.

7.4.2 MINK DISTURBANCE INDEX

The mink disturbance index is a theoretical index, based on the proportion of the lakeshore that is developed and the level of human activity as measured by the amount of cottage use in July, the peak month for cottagers. It is assumed that as the amount of developed shoreland increases, as indicated by the number of developed segments, the degree of mink disturbance also increases. It is also assumed that the degree of disturbance is intensified by greater human activity which is associated with the higher number of user-days in July (Figure 7.6).

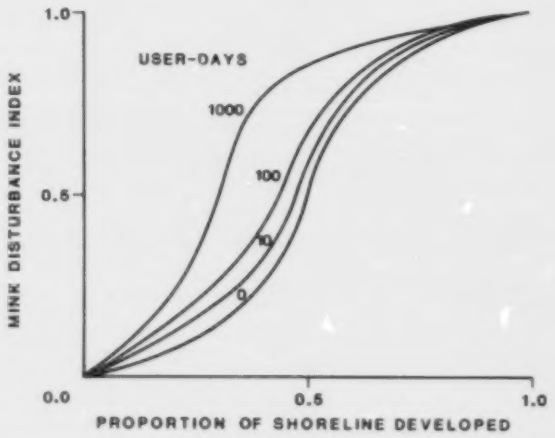


Figure 7.6 Mink disturbance index as a function of lakeshore cottage development and number of user-days during critical month (0 = shoreline developed but no occupants during the month)

7.5 SONGBIRDS

Songbird habitat is dependent upon forest cover type, which is classified as deciduous, mixed or coniferous. New forest edge, created by clearing vegetation for cottage development, changes the bird community structure and species composition. Whereas the robin can utilize a wide range of conditions from lawns to less disturbed forest habitat, other species, such as the red-eyed vireo, require mature trees.

The songbird portion of the model is based on the assumption that the probability of finding a breeding pair of birds on a given segment is related to the degree of disturbance on the segment and the degree of disturbance on adjacent segments. Shoreland segments for the songbird portion of the submodel extend inland 100 m, instead of 50 m, from the shoreline.

7.5.1 DETERMINING THE PROBABILITY OF FINDING A BREEDING PAIR OF BIRDS

For each species, the probability of finding a breeding pair of birds on a given segment depends on four factors: 1) the forest type, 2) the size of the segment, 3) the degree of development on that segment, and 4) the number of adjacent segments that are developed. Table 7.1 shows the likelihood of finding ovenbirds on a 100 ×

100 m segment. For example, on an undeveloped segment with deciduous forest and no adjacent segments developed, the likelihood of finding a pair of ovenbirds would be 0.6 or 60%. On a heavily developed segment with the same type of forest, the value is reduced to 0.2 or 20%.

Table 7.1 Likelihood of finding a breeding pair of ovenbirds on a 100 × 100 m segment, for different forest types and levels of disturbance

Area Development Index/6.0	DECIDUOUS Number of Adjacent Segments Disturbed			MIXED OR CONIFEROUS Number of Adjacent Segments Disturbed		
	0	1	2	0	1	2
0.0	0.6	0.5	0.3	0.9	0.7	0.5
0.100 – 0.349	0.3	0.3	0.3	0.5	0.5	0.5
0.350 – 0.500	0.2	0.2	0.2	0.4	0.4	0.4

The probabilities were determined by the research team and have been programmed into the submodel code for 19 songbird species. Included among the species are representatives of the flycatchers, thrushes, warblers and finches.

After the probabilities are calculated, the submodel compares them to a critical value for each species. If the likelihood is greater than the critical value, the segment is considered suitable and at least one breeding pair is added to the total expected number of breeding pairs for that species. If the likelihood is less than the critical value, the segment is assumed to be unsuitable. In this way, the number of suitable segments for each songbird species can be calculated. The lakewide number of breeding pairs of each species is the sum of the probabilities for a given species on all segments around the lake.

7.5.2 COEFFICIENT OF COMMUNITY

The Coefficient of Community (CC) or the Jaccard index (Jaccard 1932) measures the degree to which the species composition on a study plot resembles that of the most highly disturbed plot.

For each study plot a CC was calculated using the following equation:

$$CC = [c/(a + b - c)] * 100 \quad (7.5)$$

where CC = Coefficient of Community;
c = number of bird species common to both plots;
a = number of bird species in most highly developed plot; and
b = number of bird species on the sample plot.

The CC was broken down by the dominant forest cover types on the study plots, i.e. coniferous (including mixed plus coniferous) or deciduous and then related to the ADI/6 (Figure 7.7).

The resulting regression equations are:

$$CC_{conif.} = 65(ADI/6) + 14.9 \quad (7.6)$$

and

$$CC_{decid.} = 50(ADI/6) + 34.4 \quad (7.7)$$

The Coefficient of Community is estimated for each segment, using the regression relationships shown in Figure 7.7. The submodel calculates the proportion of change in the Coefficient of Community from its initial state, i.e. the native songbird community. The number of segments in which the change is greater than a critical value are summed. The total number of segments where the Coefficient of Community has changed by more than the critical value is a measure of how the songbird community around the lake has been altered.

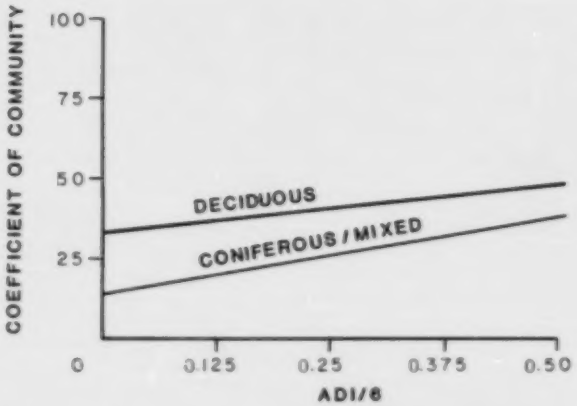


Figure 7.7 Regression lines for estimating the Coefficient of Community

7.6 LOONS

The location of each potential loon nesting site is stored in the model. It is identified by the lakeshore segment number in which the nesting site is located. In addition, the number of loon nesting islands are identified. Each of the shoreline loon nesting sites and loon nesting islands is assigned a loon nesting potential (a value between 0 and 1). Initially, each is given a value of one, the highest potential. When a segment is developed, the loon nesting potential for each shoreline nesting site is recalculated, based on the distance between the closest boundaries of the segment with the loon nest and the segment being developed (Figure 7.8). The distance is set to zero when the development and the loon nest occur on the same segment.

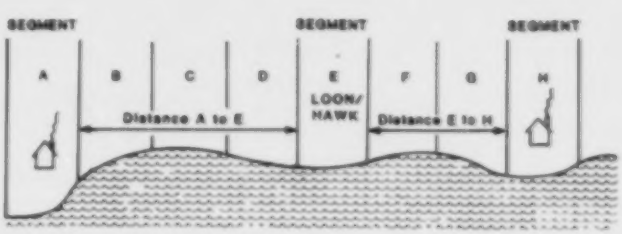


Figure 7.8 Distance measurements used in calculating loon or hawk nest disturbance from development on segments A and H

Once the distance to the nearest developed segment is determined, each potential nesting site is assigned a value. For distances equal to or greater than the safe distance, the loon nesting potential is not affected; for distances less than the minimum distance, the loon nesting potential is zero (Figure 7.9). When the nest is located between the minimum and safe distance from a developed segment, the nesting potential is set at a value proportional to its location between the designated minimum and safe distances.

When the minimum and safe distances are set at the same value (e.g. 250 m), the loon nesting potential will be zero if the distance is less than the specified value and one if the distance is greater than or equal to the specified value. On the recommendation of the Wildlife Component, both the minimum and safe distances are set at 250 m in the submodel.

Once the loon nesting potentials for all shoreline nesting sites are determined, they are added to the number of loon nesting islands to yield a loon nesting potential for the entire lake.

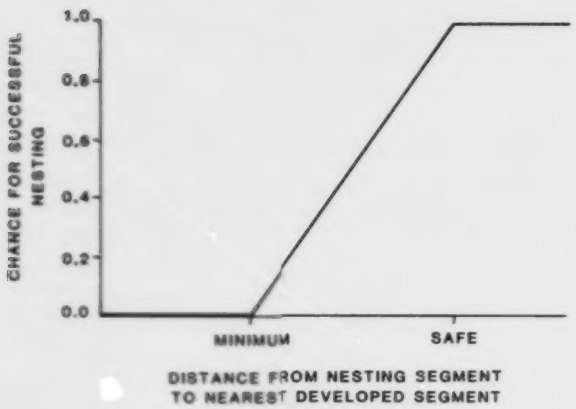


Figure 7.9 Relationship of distance (m) from the nesting segment to the nearest developed segment and the probability of successful loon and hawk nesting

7.7 HAWKS

The location of broad-winged hawk nesting valleys is also recorded in the model, by the segment numbers in which they are found. Each of the hawk nesting valleys is initially given a hawk nesting potential of one. This value is then recalculated based on distance, in a manner analagous to loon nesting sites. The distance is determined as in Figure 7.8. For distances greater than or equal to the safe distance, the hawk nesting potential is not affected; for distances less than the minimum distance, the hawk nesting potential is zero. Nests located between these two points are assigned a proportional value. On the recommendation of the Wildlife Component, both the minimum and safe distances for the broad-winged hawks are set at 150 m.

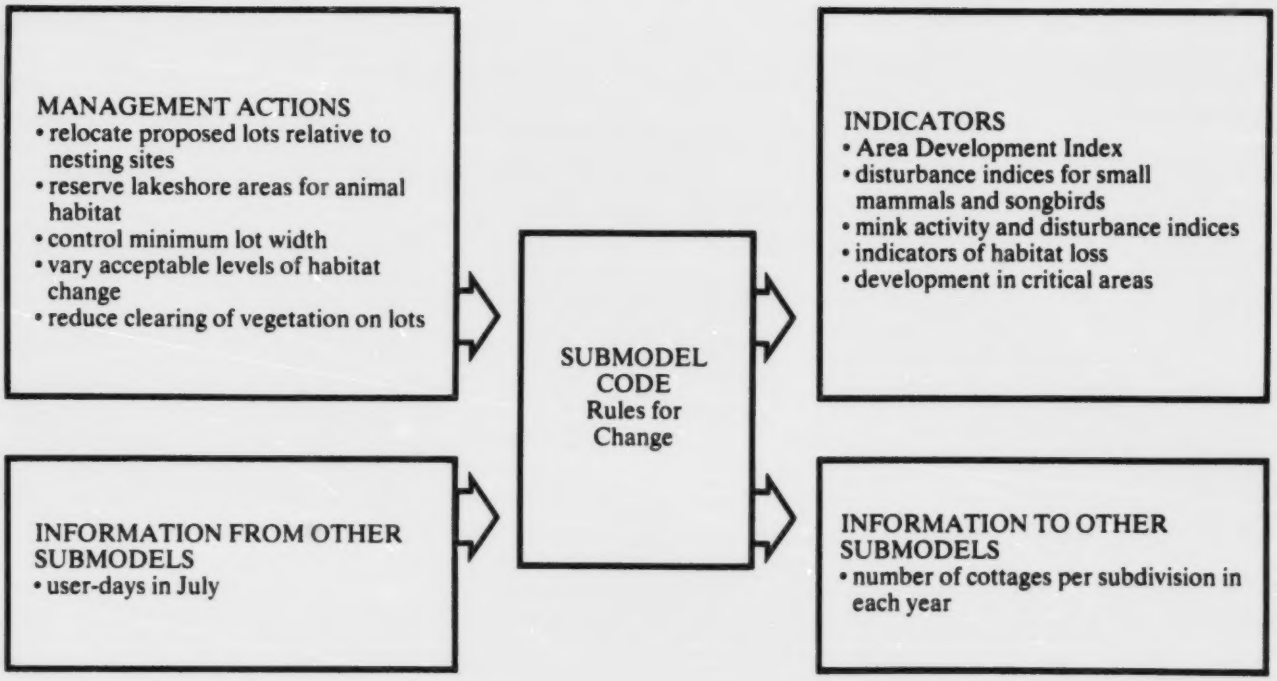
7.8 CRITICAL WILDLIFE HABITAT

The user supplies the submodel with the location of deer-yards, turtle nesting areas and streams, by segment number. The submodel records and supplies, as output, the number of designated segments with critical habitat that have been developed and when, during the simulation, this development took place.

The Wildlife Component research indicated that cottage development in winter deer concentration areas disrupted this habitat and reduced its suitability for deer. Natural turtle nesting sites should be preserved. Streams were also considered critical habitat, as they provide valuable nesting, feeding and shelter areas as well as travel lanes for many wildlife species.

7.9 SUMMARY

The Wildlife-Habitat Submodel provides predictions of the impact of cottage development on the lakeshore wildlife and wildlife habitat. The submodel simulates the impact of existing and proposed cottages and can be altered in accordance with a range of user-specified management actions. Information generated in the Land Use Submodel and relevant input data are used in the Wildlife-Habitat Submodel to produce indicators of change in the lakeshore wildlife community. The following input-output box diagram summarizes these submodel elements.


MANAGEMENT ACTIONS
• relocate proposed lots relative to nesting sites
• reserve lakeshore areas for animal habitat
• control minimum lot width
• vary acceptable levels of habitat change
• reduce clearing of vegetation on lots
INFORMATION FROM OTHER SUBMODELS
• user-days in July
SUBMODEL CODE
Rules for Change
INDICATORS
• Area Development Index
• disturbance indices for small mammals and songbirds
• mink activity and disturbance indices
• indicators of habitat loss
• development in critical areas
INFORMATION TO OTHER SUBMODELS
• number of cottages per subdivision in each year

8. FUTURE MODEL REFINEMENTS

The Ontario Lakeshore Capacity Simulation Model (OLCSM) is a simplified representation of a dynamic ecosystem. Only those elements that are necessary to simulate lake and lakeshore conditions are included. While the model does not provide answers to all the questions considered by planners in reviewing a subdivision proposal, it does substantially reduce the number of unknowns with respect to future environmental impacts.

8.1 KEY FEATURES OF THE PRESENT VERSION OF THE OLCSM

The OLCSM unites the various methods of prediction developed by the Lakeshore Capacity Study research teams, to provide a single practical tool for estimating the environmental change associated with cottage development on the lakeshore.

One of the advantages of linking these separate submodels into one integrated model is that it precludes using inconsistent data, which can occur if each submodel is operated independently. In the simulation model, all submodels draw data from the same input form, thus ensuring a consistent data base.

The environmental impact of lakeshore cottage development is measured in terms of a selected group of indicators, which are the most significant variables in the land-lake system for evaluating responses to development (Table 8.1). The values of these indicators describe the extent of the impact.

The model provides an objective estimate of environmental impact. It is not designed to make judgments about the numerical limits of the indicators. These are determined by the user, in the context of policy and technical guidance governing the particular situation.

A major feature of the model is its ability to respond quickly. This is possible because availability of data was one of the criteria applied in selecting the input requirements for each submodel.

Another practical advantage of the simulation model is its ability to test the effects of various management strategies. The user can introduce or terminate a particular strategy at any time during the simulation period, in order to determine whether a potential environmental problem can be solved by mitigative measures.

The OLCSM is designed to be flexible and easily modified. Experimental changes in the value of any variable are possible at any time during the simulation, as are modifications and additions to the model code. These various features create a powerful environmental planning tool.

Table 8.1 OLCSM indicators most sensitive to changes in the values of key variables and parameters

Submodel	Key Variables and Parameters	Most Sensitive Indicators*
Land Use	Number of cottages	Cottage-days
	Travel mode	User-days
	Cottage typology	
Water Quality	User-days	Mean ice-free period phosphorus concentration
	Lake surface area	Mean summer chlorophyll *a* concentration
	Phosphorus sedimentation rate	Hypolimnetic oxygen concentration
	Extent of spring and fall turnover	
Fisheries	Lake surface area	
	Mean ice-free period phosphorus concentration	Fishing effort (by species)
	Fish population growth rate	Fish harvest (by species)
	Catchability coefficient	Fish biomass (by species)
	Summer fishing-days	
	Fishing effort allocation by species	
Wildlife-Habitat	Lot area	Area Development Index
	Coniferous tree cover	Small Mammal Index (by species)
	Minimum and safe distance between potential nesting site and development	Mink Index
		Songbird Index (by species)
		Loon nesting potential
		Hawk nesting potential

* Based on Sensitivity Analysis (Appendix B)

8.2 AN EXAMPLE OF MODEL SIMULATION

The method of predicting, interpreting and mitigating the impact of cottage development on a hypothetical lake in the Muskoka-Haliburton area is illustrated in the example in Appendix C. The model was run for six different scenarios: first, with existing development; second, with proposed development added; and thereafter with selected mitigative measures. The predictions for selected indicators, shown on line graphs, are interpreted in the text.

Other examples could be used to demonstrate that the same number of cottages might have quite a different impact on another lake with different lake and watershed characteristics. In addition, if cottages are built on an upstream lake, they may increase the phosphorus concentration in the lake and in the outflow streams, thus possibly affecting the cottage capacity of the downstream lake.

The effects of variations in such factors as number and location of cottages, type of cottage access, timing of construction, lake and watershed characteristics, type of wildlife habitat and selection of management strategies can all be simulated by applying the OLCSM. The resulting predictions of probable impact can assist planners in guiding development in ways that will avoid damage to the inland lake environment.

8.3 RECOMMENDED FUTURE REFINEMENTS

The refinements specifically identified in the descriptions of the submodels (Chapters 4-7) should improve the model's predictive capability. Therefore, the next version of the OLCSM should include as many of these refinements as possible.

With respect to water quality, the new equations developed by the Trophic Status Component group, for gross phosphorus export and lake phosphorus retention, should be incorporated into the simulation model. Further, the prediction of depth-related minimum oxygen values for the hypolimnion would strengthen the linkage between the Water Quality and Fisheries submodels, because of its importance in defining fish habitat.

In the Fisheries Submodel, the method of estimating the catchability coefficient should be improved or replaced, as the fish harvest prediction depends heavily on this parameter. In addition, the choice between the two methods of predicting fishing effort needs to be resolved.

The quantitative linkage between cottage development and alterations in the littoral zone, coded in the Wildlife-Habitat Submodel, requires further work by the Ministry of Natural Resources. As the framework for including these relationships in the OLCSM is in place, it would be relatively simple to incorporate new predictive equations when they are available.

Finally, the influence of acidic precipitation on water quality, fish and wildlife is not included in the submodels because, at the time the OLCSM was developed, predictive equations were not available. Research on acidic precipitation is now contributing to a better understanding of these relationships. By incorporating relevant scientific findings in the model, its value could be enhanced for lakes that are acid stressed or sensitive to acidic precipitation.

8.4 SUMMATION

To sum up, the Ontario Lakeshore Capacity Simulation Model is not intended to be immutable. The present version (1982 methods) is capable of predicting the environmental impact of lakeshore cottage development and simulating the effects of various mitigative measures. The next version, including some or all of the recommended refinements, should be tested on lakes with extreme conditions to ensure that it responds to the full range of conditions in the Study Area. Subsequent versions of the OLCSM should be up-dated as required to reflect future advances in the scientific understanding of lake ecosystems.

GLOSSARY

The terms and symbols are defined in the way they are used in this report.

Actions
Lake planning/management strategies.

Algorithm
A rule or series of steps for obtaining a solution to a problem, e.g. Add four numbers ...

Angler-hour
A unit of measurement of fishing pressure describing one angler spending one hour fishing.

Anthropogenic
Generated from human activities.

Areal Hypolimnetic Oxygen Deficit (AHOD)
The oxygen depletion rate in the hypolimnion per unit area, per unit of time, e.g., $mg \cdot m^{-2} \cdot day^{-1}$.

Baseline Condition
A term used to describe the state of a system (e.g. a lake) before any hypothetical changes are made in the lake parameters.

Biomass
Mass of living matter in a given space, e.g. fish biomass in a lake ($kg \cdot ha^{-1}$), or algae biomass per unit volume of water ($mg \cdot m^{-3}$).

Carrying Capacity (K)
The maximum number of organisms (e.g. fish) supported in a given habitat (e.g. a lake) under optimum conditions.

Chlorophyll *a* (CHLOR)
The concentration of the pigment chlorophyll *a* in lake water; a measure of the density of the microscopic free-floating algae (phytoplankton) and primary production in the lake.

Cluster Development
Type of development in which cottage lots are located in groups back from the shore with the adjoining lake frontage providing common shore access.

Computer Code
The logical series of instructions that tells the computer to perform prescribed operations.

Computer Run
The complete execution of all operations of a computer program so that the output or result is produced.

Cottage
A single-family residential building located on the lakeshore or in close proximity to a lake.

Cottage-day
A unit of measurement for cottage use: one cottage in use for one day.

Critical Value
Value of a wildlife indicator variable, indicating that the changes in wildlife habitat threaten either the existence of a wildlife species on the lakeshore or the maintenance of self-sustaining wildlife communities on at least some portion of the lakeshore.

Deer Yard
An area of land where deer congregate in the winter.

Deterministic Model
A model that produces unique output for each set of input data, such as a series of regression equations.

Dissolved Oxygen
The concentration of oxygen in lake water, usually measured in $mg \cdot L^{-1}$ of water.

Driving Variable
In computer modelling terminology, a variable that has a major effect on the output from a model run, e.g. user-days.

Ecological Niche
All interrelationships of a species with its environment, e.g. feeding requirements, habitat and territory.

Ecosystem
An interdependent complex of prevailing environmental factors and biological organisms, e.g. tundra, forest and lake-watershed ecosystems.

Enrichment
The increase in the nutrient concentration of a lake, which stimulates the growth of aquatic life, e.g. plankton, plants.

Fishing Effort
The time spent fishing, usually expressed as angler-hours $\cdot ha^{-1}$ of lake surface.

Flushing Rate (ρ)
The number of times per year (or season) that the water in a lake is completely replaced by inflow from upstream or some other source.

Gaming
Simulating hypothetical conditions in order to understand the direction and magnitude of system responses to stress.

Grid-system
The grid-system is formed from the division of the lakeshore into wildlife segments of uniform width. (See Lakeshore Wildlife Segment)

Hypolimnion
The bottom, non-circulating layer of a lake stratified by temperature.

Indicators
Variables which provide a measure of the health of (or change in) the ecosystem under study, when they are monitored over time.

Indicator Species
Selected animal species included in the OLCSM. The model predicts the impact of development on these species.

Instantaneous Fishing Mortality (F)
The proportion of the fishery removed from the lake per unit of time by anglers (calculated over a short interval of time when fish stock remains at a steady level).

Instantaneous Natural Mortality (M)
The proportion of the fishery that dies due to natural causes per unit of time (calculated over a short interval of time when fish stock remains at a steady level).

Iteration
The repetition of a set of tasks. In the OLCSM, it is each new cycle through some or all of the statements in a computer program.

Lake Morphometry
The physical dimensions of a lake, such as depth, length of shoreline, volume of water.

Lakeshore
In the OLCSM, the lakeshore is defined as shoreland up to 50 m inland from the shoreline of a lake.

Lakeshore Wildlife Segment
When the lakeshore is divided into sections of uniform width (ranging from 50 – 200 m) for the compilation of shoreland habitat data in the OLCSM, each section becomes a lakeshore wildlife segment.

Land Use
The type of use of an area, in this case, the lakeshore, e.g. residential, recreational, agricultural or forest land use.

Littoral Zone
The nearshore shallow water zone of the lake, where light penetrates to the bottom.

Littoral Zone Segment
A segment formed when the littoral zone is divided into sections of uniform width (ranging from 50 – 200 m) for the compilation of littoral zone habitat data.

"Looking Outward"
AEAM Workshop exercise in which information from each of the subsystems is identified by the participants as being required by subsystem x in order to predict its behaviour.

Lot
The part of the registered lot located within the 50-m band of shoreland adjacent to the lake, which is important to wildlife. (Not a registered lot!)

Lot Area
The area of a lot, i.e. lot width (m) multiplied by 50 m.

Management Scenario
A set of hypothetical management strategies designed to reduce the impact on the environment.

Model
An abstraction or simplification of a system.

Multi-tier Development
Development with more than one tier of cottage lots.

Multivariate Statistics
Statistical procedures used to analyze a data set composed of more than one independent and one dependent variable.

Official Plan
A local or regional document, approved under the *Planning Act* by the Ontario Minister of Municipal Affairs, containing objectives and policies established primarily to guide the physical development of a municipality (or part of a municipality), region or unorganized area, while recognizing relevant soil, economic and environmental conditions.

Parameter
In modelling terminology, a constant or slowly changing value that describes a part of the system, e.g. number of kg of phosphorus produced per capita per day.

Phosphorus Binding Capacity (PBCAP)
The amount of cottage-generated phosphorus (mg) that can be retained in the septic system tile bed and in the soil between the cottage and the lake.

Phosphorus Leakage Rate (RLEAK)
The proportion of the cottage-generated phosphorus that leaks to the lake in each season.

Phosphorus Load
The amount of phosphorus per unit of lake surface area entering the lake from all sources, including the watershed drainage, precipitation, upstream lakes and cottages.

Phosphorus Settling Velocity
The amount of sedimentation (m) from the water column per unit of time.

Phosphorus Supply
The total amount of phosphorus entering the lake from all sources, including the watershed drainage, precipitation, upstream lakes and cottages.

Regression
Statistical procedure used to construct an equation with which one can predict values of one variable in terms of one or more other variables.

Secchi Depth
A measure of water transparency; the depth (m) at which a Secchi disc, when lowered into the water, becomes invisible.

Simulation
In modelling terminology, the prediction of changes that occur (under a specified set of conditions) in a system over time.

Single-tier Development
Lakeshore cottage development with one row of cottage lots.

Songbird Likelihood
The probability of finding a particular species of songbird on a lakeshore segment.

Spatial Extent
The geographical area for which the model was designed, i.e. the Muskoka-Haliburton area of Ontario.

Spatial Unit
The unit of land for which the model simulates during a computer run, i.e. in the OLCSM, a single lake surrounded by a 50-m deep band of shoreland.

Stochastic Model
Model with algorithms for natural (random) variation that affects output, e.g. amount of precipitation or seasonal temperatures.

Stratification
Layering of deep lakes by temperature gradients formed by rapid warming of surface waters in spring.

Study plot
Site used for sampling vegetation or observing wildlife (or signs of wildlife activity).

Subdivision
The division of a parcel of land into building lots according to a proposed plan which requires approval under the *Planning Act* before the lots can be registered. The term "subdivision" is also used in the text, under certain specified conditions (i.e. with reference to the land use equations), to describe a group of lots with the same travel mode.

Symbols

Σ Summation

$kg \cdot m^{-2}$ An example of metric notation used throughout the report; the symbol is expressed as kilograms per square metre.

System
A complex of organized connected parts; in the context of this report, the lake-watershed system.

Time Horizon
Time period over which projections are made on the state of the system, e.g. 10 years, 20 years.

Time Step
Interval of time between model iterations, e.g. monthly, yearly.

Trophic Status
The degree of fertility of a lake, usually characterized by the amount of plant production.

User-day
A unit of measurement for cottage use: one cottage in use for one day by one person.

User-defined Constant
Parameter that does not change over time (or changes so slowly that it can be treated as a constant if re-evaluated periodically) and can be easily changed by the user to more accurately describe known conditions on a given lake or to game with the model.

Variable

Continuous: A variable that can assume any value with defined limits, e.g. length, weight, amount of rainfall.

Discrete: A variable that can only change by integer (whole number) amounts, e.g. number of cottages on lake, number of fish/ha.

Watershed
Drainage area comprising all land surfaces that drain (directly or through streams) to a lake.

Zooplankton
The predominantly microscopic aquatic animals that drift and float at various depths in water.

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APPENDICES

APPENDIX A. WORKSHOP PARTICIPANTS

APPENDIX B. MODEL SENSITIVITY ANALYSIS

APPENDIX C. AN EXAMPLE OF MODEL APPLICATION

APPENDIX A. WORKSHOP PARTICIPANTS

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Table B.1 Conditions used in the sensitivity analysis simulation runs

Variable Names	CONDITIONS FOR EACH LAKE SIMULATION RUN													
	1[g]	2	3	4	5	6	7	8	9	10	11	12	13	14
Mean depth (m)	12.5	*	*	25	12.5	25	25.0	12.5	*	*	*	*	*	*
Surface area (ha)	338		820	820	820	338	820	338						
Watershed area (ha)	1208	4800	1208	1208	4800	1208	4800	1208						
AHOD equation ($mg \cdot m^{-2} \cdot d^{-1}$)	Charlton				Cornett-Rigler			Charlton						
Settling velocity (yr^{-1})	7.4							5.4	9.4	12.4	7.4			
Seasonal settling velocity	0,4.7,0.3,2.4							0,3.4,0.22,1.78	0,6,0.38,3.0	0,7.93,0.5,3.97	0,4.7,0.3,2.4			
Development rate (yr^{-1})	0.20													
Spring oxygen ($mg \cdot L^{-1}$)	10.4										7.8	10.4	10.4	10.4
Fall oxygen ($mg \cdot L^{-1}$)	10.0										10.0	7.8	6.8	10.0
IDRAIN[a]	1													
Cottage-day equation	Accessibility													
CPLK[b] ($\mu g \cdot L^{-1}$)	0.										4.5	0.0		
CMIN[c]	0.													
IHEAD[d]	2													
LT[e] growth rate (yr^{-1})	0.33	0.22	0.44	0.33	0.55	0.33								
SMB growth rate (yr^{-1})	0.50	0.40	0.60	0.50	0.70	0.50								
Proportion of MSY to LT	0.25							0.35	0.45	0.55	0.25			
Proportion of MSY to SMB[f]	0.50													
LT catchability coefficient	0.01										0.05	0.10	0.005	0.01
SMB catchability coefficient	0.0034													
Septic system (1-3) %	0., 95., 5.0													
Natural variation	No													Yes

* Where there is no entry, the condition is the same as in the immediately preceding Lake Simulation Run.

a IDRAIN = 1 if sub-basins exist and their surface areas are known; 0 if sub-basin calculation is not used.
b CPLK = measured initial spring P concentration.
c CMIN = proportion of lots not developed.
d IHEAD = is lake a headwater lake? (2 = yes)
e LT = Lake Trout
f SMB = Smallmouth Bass
g Run 1 = baseline conditions
Run 2-14 = altered conditions

MODEL SENSITIVITY ANALYSIS

Sensitivity analysis is performed in order to determine the set of parameters and variables that influence predictions the most. By using a specialized technique, one can determine the level of error in the parameters that can be permitted before the prediction error becomes unacceptable. In this appendix these parameters and variables are identified and their relationships to selected indicators are described. The sensitivity testing was performed by answering three questions:

1. If one of the driving variables, such as the number of cottages, is changed by one unit, how is that reflected in the indicators generated in the responding submodels?
2. If the input variables such as number of cottages (existing), lake depth or lake surface area, are inaccurately measured, will this cause large errors in the indicators?
3. If some of the assumptions built into the model are incorrect, how much change can be expected in the indicators? What are the key assumptions, variables and parameters of the model?

B.1 METHODOLOGY

A widely applied approach to sensitivity analysis is based on perturbation theory (Tomovic and Karplus 1963). Perturbation theory prescribes that each key parameter is varied about its mean value[1], keeping everything but the parameter or group of parameters unchanged. In this way, the sensitivity to the controlled manipulation of the input parameters of the indicator variables can be determined.

In this analysis, one lake was used and new values were assigned (one at a time) to a set of parameters as a surrogate for the use of different lakes with a range of characteristics. The model was then run after each change and the output was examined (Table B.1). The OLCSM is basically a linear model, that is, variables are related directly and respond either in the same direction or inversely to the perturbed variable. The testing, therefore, was confined to the dominant or controlling variables, such as phosphorous concentration and fishing effort, and selected indicators, such as hypolimnetic oxygen deficit and fish biomass.

As the focus of this work is the impact of cottage development, the sensitivity of major submodel indicators to an increase in development by one unit (a cottage) was analyzed, thus establishing "change per unit-of-loading" rates.

[1] The classical approach requires that all parameters be tested individually and in all combinations using a set of sensitivity equations. A sensitivity equation is created by breaking a mathematical relationship down to its basic components. For example, a hypothetical predictive equation in the model might be:

$$YX = AA + 4.5B$$

where $$AA = \frac{6000 - C + ALD}{MM3}$$

and $B = 7/WX$, $C = 34 + MM1$, $ALD = XX/4$.

Thus the sensitivity equation, using substitution, would be:

$$YX = (6000 - 34 + MM1 + XX/4) / MM3 + 4.5\,(7/WX)$$

B.2 LAND USE (COTTAGE USE)

The sensitivity analysis of the Land Use Submodel was restricted to the Land Use Component predictive equations. As this submodel generates data on the source of the impact, only points 2 and 3 discussed in the introduction apply here.

The land use indicators, cottage-days and user-days, are calculated using two equations in the Land Use Submodel (Section 4.2). These key formulae are multiple regression equations with both dichotomous and continuous variables. Dichotomous variables are used to describe "either-or" situations and take a value of one or zero only. Therefore, any number preceding this type of variable, e.g. 93.452 * TMODE1, is either included if TMODE1 equals 1 or left out of the prediction if the value is zero. Continuous variables are those which take on any numerical value.

In Equation 1 (Table B.2), TMODE1-3 are dichotomous variables such that, if TMODE1 = 0, 93.452 cottage-days are not used in the annual prediction (however, TMODE2 or TMODE3 will be used). Obviously, giving the wrong value to a dichotomous variable can have a very significant impact on the annual cottage use prediction. To illustrate, using Equation 1 and setting MAXPOORX = 0.4 and DISTSUMH = 4.0, if the travel mode is misidentified as TMODE2 instead of TMODE1, the estimate of cottage-days per cottage is 71 days less than with the TMODE1 value (177 days), which represents a 40% difference.

Table B.2 Equations for predicting annual cottage-days, and the associated cumulative coefficient of determination (R^2) for the variables in the two equations. Equations and data taken from Downing (1986).

ACCESSIBILITY EQUATION (Equation 1)

Annual Cottage-days = 83.105 + 93.452 TMODE1 + 0.322 MAXPOORX – 0.529 DISTSUMH + 22.655 TMODE2 + 21.972 TMODE3

Variable Name	Regression Coefficient	Cumulative R^2
TMODE1	93.452	0.250
MAXPOORX	0.322	0.328
DISTSUMH	–0.529	0.332
TMODE2	22.655	0.337
TMODE3	21.972	0.340

COTTAGER EQUATION (Equation 2)

Annual Cottage-days = 68.312 + 278.578 PERM + 102.042 ESUMMER + 21.291 TMODE1 + 12.623 TMODE2 – 0.191 DISTSUMH

Variable Name	Regression Coefficient	Cumulative* R^2
PERM	278.578	0.838
ESUMMER	102.042	0.911
TMODE1	21.291	0.918
TMODE2	12.623	0.919
DISTSUMH	–0.191	0.920

* R^2 values prior to benchmarking. With benchmarking, the accuracy of the predictions from the two equations is comparable.

The sensitivity of the cottage-day prediction to changes in the independent variables can be determined by examining the regression coefficients and their associated coefficients of determination (R^2). In Equation 1, TMODE1 has a coefficient of 93.452, suggesting that the cottage-day estimate is extremely sensitive to this variable. However, MAXPOORX, with a coefficient of 0.322, has little influence on the final prediction. With regard to R^2 values, TMODE1 alone explains 25% of the variability in the predicted cottage-days while MAXPOORX explains only 7.8% of the variability in the estimate.

In the Land Use Submodel, when using Equation 1 (Table B.2), the predictions are affected most by changes in the TMODE variables, while in Equation 2 (Table B.2) the predictions are influenced most by changes in the cottage typology proportions for PERM and ESUMMER, two continuous variables.

The remaining relationships within the Land Use Submodel, albeit important, did not lend themselves to the sensitivity testing that was conducted.

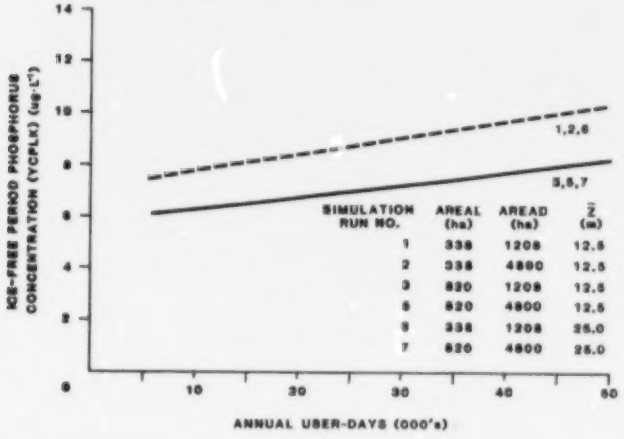

ICE-FREE PERIOD PHOSPHORUS CONCENTRATION (YCPLK) (ug·L⁻¹)
ANNUAL USER-DAYS (000's)
1,2,6
3,5,7
SIMULATION RUN NO. AREAL (ha) AREAD (ha) Z̄ (m)
1 338 1208 12.5
2 338 4800 12.5
3 820 1208 12.5
5 820 4800 12.5
6 338 1208 25.0
7 820 4800 25.0

Figure B.1 Relationship of ice-free period phosphorus concentrations (YCPLK) to annual user-days, as lake surface area (AREAL), watershed area (AREAD) and mean depth ($\bar{Z}$) are altered

B.3 TROPHIC STATUS

B.3.1 WATERSHED MORPHOLOGY, COTTAGE USE AND PHOSPHORUS

How sensitive is the Water Quality Submodel to changes in the number of cottages, cottage-days and user-days and what are some of the associated parameters which play a significant role in the phosphorous prediction? As an example, using the actual conditions on the test lake which has a small watershed and a flushing rate of 0.14 yr^{-1}, one cottage unit, receiving 500 user-days of use per year, increased P concentrations by 0.039 $\mu g \cdot L^{-1}$ (Table B.3). The increase is somewhat less on larger lakes due to the greater dilution of the cottage P input (Table B.3).

Phosphorus supplied from sub-basins, i.e. inflow streams, can be calculated by the model in two ways: by using either a global average or a figure based on the sum of all the sub-basin surface areas. Varying the sub-basin area by as much as 75 ha did not affect the phosphorus prediction; in fact, the P values for the baseline and the perturbed scenarios were identical. However, as the error in the measurement of the sub-basin area grows a discrepancy in P values will appear.

Of the three parameters (lake area, watershed area and mean depth) that were changed, ice-free period phosphorous concentrations were most sensitive to variations in lake surface area (Figure B.1). A doubling of the mean depth alone had no influence on P concentrations.

The relationship between units of cottage use and increases in lake nutrients and algal growth will vary between lakes. Soil characteristics and size and age of the development will also influence the amount of nutrients reaching the lake as a result of the soil phosphorus retention capability.

Table B.3 Effect of lake morphometry and watershed size on the relationship between cottage use and lake phosphorus concentration.

Lake Simulation Run	Lake Surface Area (ha)	Watershed Area (ha)	Lake Mean Depth (m)	Predicted User-Days* per Cottage per Year	Annual Increase in Mean Ice-Free Period P ($\mu g \cdot L^{-1}$) per Cottage
1	338	1208	12.5	500	0.039
2	338	4800	12.5	500	0.030
6	338	1208	25.0	500	0.039
3	820	1208	12.5	500	0.018
5	820	4800	12.5	500	0.017
7	820	4800	25.0	500	0.016

* Prediction is the average of all cottages on this lake. User-days per cottage in the Study Area vary from approximately 100-800 user-days per year (Downing, pers. comm. 1983). The global average for the Land Use Component study lakes is 356 annual user-days per cottage.

B.3.2 COTTAGES, CHLOROPHYLL *a* AND SECCHI

In the test lake, with a small surface area and watershed area, one cottage with 500 user-days per year (range in Study Area is 100-800) raised the chlorophyll *a* level by 0.01 $\mu g \cdot L^{-1}$. The combined approximate doubling of the lake surface area and quadrupling of the watershed area (Run #5) indicated a much reduced rise in the chlorophyll *a* concentration in response to an increase in user-days (Figure B.2).

Secchi disc values are derived using the formulation provided by Scheider (1979) where

$$SECCHI = 5.21/CHLOR^{0.41} \qquad (B.1)$$

where SECCHI = Secchi depth (m); and
CHLOR = chlorophyll *a* concentration (mg^{-1})

The sensitivity of Secchi to changes in the number of cottages is dampened by at least two filters: the phosphorous – chlorophyll *a* relationship and the chlorophyll *a* – Secchi relationship. Not surprisingly, a substantial change in the number of cottages is required to produce a significant change in the Secchi depth. In the test lake with baseline conditions (Run #1), an increase of 86 lakeshore cottages (between the start and end of the simulation) reduced the Secchi depth by 0.8 m. (Table B.4).

B.3.3 SEDIMENTATION OR SETTLING VELOCITY

To determine the lake phosphorus concentration for any given period, phosphorus losses and gains must be accounted for. A certain amount of phosphorus settles out of the lake, contributing to a reduction in the water-column phosphorus level. *How sensitive is the phosphorus prediction to changes in the rate of phosphorus sedimentation or the settling velocity?* As the model requires both annual and four seasonal settling velocities, both levels of resolution must be examined.

The model is extremely sensitive to changes in the annual sedimentation rate (V). As the rate rises, more phosphorus settles out of the water column (Table B.5). An underestimate of the settling velocity results in a proportional rise in the phosphorus in the water column. However, an overestimate will not elicit an equally dramatic drop in the P concentration (Figure B.3).

Changes in the seasonal allocation of the annual sedimentation rate have little effect on the predictions. Higher spring and lower summer values only slightly increase the final P prediction. Furthermore, a reduction in the summer (May 16 – October 31) and a rise in winter (December 1 – March 15) sedimentation rates tend to cancel each other, yielding an only slightly elevated P concentration after the first year of the simulation.

In summary, the predictions of lake phosphorus concentration are highly sensitive to changes in annual sedimentation rates, as defined by the settling velocity. Changes, up or down, elicit inversely proportionate shifts in the predicted P values. Allocation of the annual values among the four seasons seems to have only a minor effect.

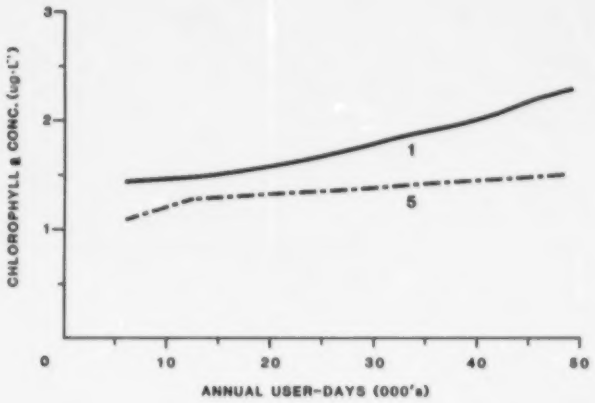


Figure B.2 Sensitivity of the chlorophyll *a* to user-days relationship, to an increase in watershed and surface area (Run #5)

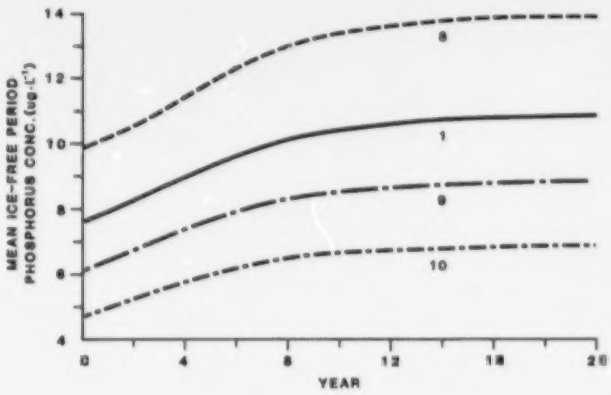


Figure B.3 Mean ice-free period phosphorus concentration as a function of time with different simulated settling velocities (Runs #8, 9 and 10)

Table B.4 Predicted Secchi and chlorophyll *a* values for four simulations. Cottages at start = 12; after 20 years = 98.

Lake Simulation Run	Lake Surface Area (ha)	Watershed Area (ha)	Lake Mean Depth (m)	Secchi Depth (m)		Chlorophyll *a* ($\mu g \cdot L^{-1}$)	
				Start	After 20 yrs	Start	After 20 yrs
1	338	1208	12.5	4.5	3.7	1.43	2.27
2	338	4800	12.5	4.5	3.9	1.39	1.99
5	820	4800	12.5	5.0	4.4	1.09	1.50
7	820	4800	25.0	5.0	4.4	1.09	1.50

B.3.4 PHOSPHORUS RETENTION AND LEAKAGE RATES IN SOIL

With the existing model, P retention in the soil and the rate at which it leaks (irrespective of retention capacity) from the septic system into the receiving water can be varied. The two parameters are the soil's phosphorus binding capacity per cottage (in kg) termed CAPPC, and the annual proportion of the total human nutrient addition that leaks to the receiving water, termed RLEAK. As RLEAK rises, the maximum amount of phosphorus that can possibly accumulate in the soil drops (Figure B.4). Therefore, *how sensitive is the phosphorus prediction to changes in these two values?* The baseline conditions permit an annual leakage rate of 100% and a soil P adsorption capacity of 2.4 kg per cottage. In the test lake, after 20 years, the phosphorus prediction with baseline conditions rose from 7.6 to 10.8 $\mu g \cdot L^{-1}$ (Run #1, Table B.6 and Figure B.4). If the soil adsorptive capacity is approximately halved and the leakage rate is reduced to 0.2 (Run #7, Table B.6), the phosphorus concentration after 20 years drops by 0.2 $\mu g \cdot L^{-1}$ from the baseline simulation. An increase in the adsorptive capacity to 24.0 kg per cottage (Run #8, Table B.6), a ten-fold increase over the baseline conditions, reduces the lake phosphorus concentration by about 0.5 $\mu g \cdot L^{-1}$ from the baseline conditions. Lowering the leakage rate to 0.01 (Run #9, Table B.6) results in a drop of 1.9 $\mu g \cdot L^{-1}$ from the baseline P level.

These simulation runs suggest that changing the soil's phosphorus binding capacity per cottage has very little effect on the concentration at year 20, whereas lowering the leakage rate clearly reduces the concentration after 20 years. Actually this change is quite small, given an almost 100% reduction in the leakage rate. Neither of these factors, in their present form in the model, appear to elicit marked changes in the ice-free period phosphorus concentration.

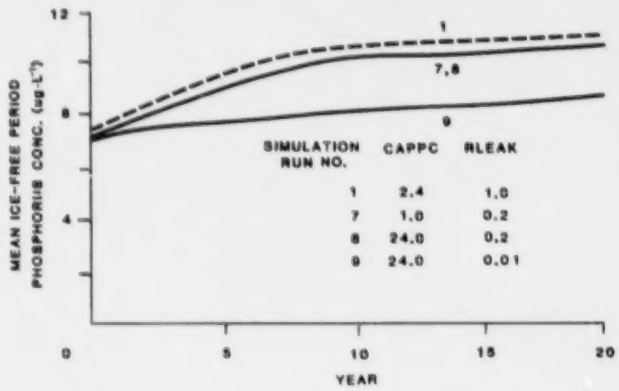


Figure B.4 Mean ice-free period phosphorus concentration as a function of changes in the soil retention capacity (CAPPC) and soil P leakage rate (RLEAK)

Table B.5 Predicted phosphorus concentrations as a function of changing sedimentation rates

Lake Simulation Run*	Lake Surface Area (ha)	Sedimentation Rates (V)					Changes in Seasonal Distribution of V Relative to Actual	Simulation Results: Mean Ice-free Period Phosphorus Concentration ($\mu g \cdot L^{-1}$)		Simulation Results: Number of Cottages	
		Annual	Seasonal Sp	Su	F	W		Start	After 20 years	Start	After 20 years
1	338	7.4	0	4.7	0.3	2.4	Actual values	7.6	10.8	12	98
8	338	5.4	0	3.4	0.2	1.8	Reduced annual V; same seasonal proportion	9.9	13.9	12	98
9	338	9.4	0	6.0	0.4	3.0	Higher annual V; same seasonal proportion	6.1	8.8	12	98
10	338	12.4	0	7.9	0.5	4.0	Higher annual V; same seasonal proportion	4.7	6.9	12	98
									After 10 years		After 10 years
H1	69	12.5	0	4.5	2.0	6.0	Actual values	5.4	14.3	0	78
H2	69	8.0	0	3.0	0.5	4.5	Reduced annual V;	5.8	18.9	0	78
H3	69	18.5	1.5	6.0	3.5	7.5	Higher annual V; same seasonal proportion	4.8	11.4	0	78
H4	69	12.0	1.0	3.0	2.0	6.0	Higher in spring; lower in summer	5.7	14.9	0	78
H5	69	12.5	0	3.0	2.0	7.5	Lower in summer; higher in winter	5.7	14.2	0	78

* 1,8,9 and 10 refer to simulation runs for the test lake (Table B.1); H1-H5 refer to a second test lake.

Table B.6 Parameter values used in analysis of the sensitivity of phosphorus and changes in CAPPC and RLEAK. Existing soil phosphorus binding capacity PBCAP(kg) = 235.2.

Lake Simulation Run	Total Number of Cottages at End of Simulation	Annual Phosphorus Contribution per Person PPC (kg)	Maximum Soil P Storage per Cottage CAPPC (kg)	Fraction of P Bound in Soil that Leaks to Lake RLEAK	Mean Ice-Free Period Phosphorus YCPLK ($\mu g \cdot L^{-1}$)	
					Start	After 20 years
1*	98	0.8	2.4	1.0	7.6	10.8
7	98	0.8	1.0	0.2	7.5	10.6
8	98	0.8	24.0	0.2	7.5	10.3
9	98	0.8	24.0	0.01	7.4	8.9

* Baseline conditions

The timing of the phosphorus release to the lake, assuming a leakage rate of 100%, revealed only slight variations in the P values after 10 years of simulation.

Three scenarios were tested against the baseline conditions (Table B.7):

a) P release uniform over all seasons;
b) P release only in the spring (via sewage lagoon); and
c) P release only in the winter (via sewage lagoon).

The resulting phosphorus predictions, when compared with the baseline values, varied by a maximum of only $\pm$ 0.5 $\mu g \cdot L^{-1}$, suggesting that changing the phosphorus release period did little to alter the final (year 10) concentration.

In conclusion, the model predictions of ice-free period phosphorus concentrations on the test lake are not sensitive to changes in seasonal (proportional) phosphorus release.

B.3.5 PHOSPHORUS AND HYPOLIMNETIC OXYGEN

The increase in the lake phosphorus concentration stimulates the growth of aquatic plants and animals. These organisms eventually die and their decomposition consumes oxygen. Decomposition takes place primarily at the lake bottom-water interface, which is the first location to become anoxic, i.e. devoid of dissolved oxygen. To make matters worse, during the major growth and die-off period, lake waters become thermally stratified, restricting the movement and exchange of water between the top layer and the hypolimnion. Therefore, hypolimnetic oxygen concentrations remain low or drop due to a lack of mixing with the oxygen-rich upper layers. As trout prefer the lower, colder region of the lake in summer and as they are quite sensitive to reduced oxygen levels, the model has been programmed to forecast changes in hypolimnetic oxygen concentration. These changes are responsive to fluctuations in the level of nutrient enrichment of the lake.

How sensitive is the hypolimnetic minimum oxygen concentration to variations in P levels as a function of changes in the number of annual user-days?

Table B.7 Predicted phosphorus, minimum summer oxygen concentrations and winter oxygen concentrations under four different simulated annual effluent release schemes*

Effluent Release Timing	Number of Cottages after 10 Years of Simulation	YCPLK		SSPC		Summer Oxygen Min.		Winter Oxygen Min.	
		Start	After 10 years	Start	After 10 years	Start	After 10 years	Start	After 10 years
		($\mu g \cdot L^{-1}$)		($\mu g \cdot L^{-1}$)		($mg \cdot L^{-1}$)		($mg \cdot L^{-1}$)	
Baseline (seasonal)	90	7.8	10.7	7.7	10.7	7.4	6.6	7.2	7.0
IEVEN = 1 steady release year-round	90	7.5	10.2	7.8	10.4	7.4	6.5	7.1	7.0
Lagoon system, all P released in spring	90	7.6	10.9	7.8	11.0	7.2	6.9	7.5	6.3
Lagoon system, all P released in winter	90	7.6	11.0	7.8	11.0	7.2	6.9	7.5	6.3

* Based on additional simulation runs on the test lake, not shown in Table B.1.

YCPLK = mean ice-free period phosphorus concentration
SSPC = mean weighted annual steady state phosphorus concentration
IEVEN = switch to even out cottage use, e.g. as for permanent residences

B.3.5.1 SUMMER

Of the two methods available in the model, the Charlton equation seems slightly more sensitive to variations in P than the Cornett-Rigler formulation. After a 20-year simulation on the test lake, the hypolimnetic oxygen concentration predicted with the Charlton equation dropped by 1.2 mg · L^{-1} with an addition of more than 3 µg · L^{-1} of phosphorus to the system (Figure B.5, Run #1). This rise in P is the result of an 8-fold increase in the user-days from the start of the simulation (Table B.8).

What may account for the different levels of sensitivity for the two equations is that the Charlton formulation uses the chlorophyll *a* value as a key measure of enrichment, whereas the Cornett-Rigler formula uses the lake phosphorus retention as its key variable. Chlorophyll *a* is a more direct measure of the algae production — hence the subsequent plankton die-off and oxidation are more clearly reflected in the AHOD predictions.

The Cornett-Rigler formulation actually predicts a slight improvement in the oxygen conditions (Figure B.5, Run #5). This is probably due, in part, to an overestimate in V, leading to reduced primary production and dissolved oxygen loss.

Thickness and temperature of the hypolimnion

Thickness (ZHYPO) and temperature (THYPO) of the hypolimnion are used in both equations. Cornett and Rigler give more weight to ZHYPO, while Charlton places greater emphasis on THYPO (Chapter 5). If these two variables are perturbed in unison, any significant change would be cancelled out.

Partial "turn-over" assumption

The present model uses the assumption that complete mixing or "turnover" of the water mass will occur every fall and spring. In reality, this may not be true, in which case, instead of starting with an oxygen level of 10.5 mg · L^{-1} in the spring and fall, the biota would have to survive with seasonal maxima of 7 or 8 mg · L^{-1}. This has profound implications for lake trout production, as values below 5 mg · L^{-1} markedly reduce trout survival.

In Run #11, a simulated partial spring turnover resulted in a severely reduced oxygen level by the second year of the simulation (Figure B.6).

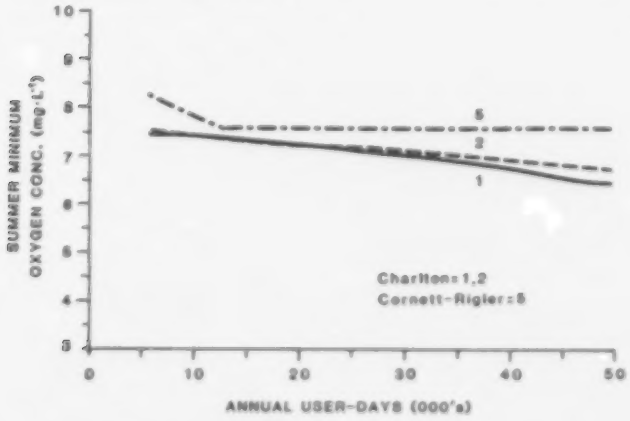


Figure B.5 Comparison of minimum summer hypolimnetic oxygen (SOMIN) prediction for the Cornett-Rigler (Run #5) and the Charlton (Runs #1 and #2) equations

Table B.8 Parameter values and indicator variable results for hypolimnetic oxygen conditions during lake simulation runs 1 and 6

Variable	Lake Simulation Run	TIME	
		Start	After 20 years
Minimum Summer Hypolimnetic Oxygen Concentration SOMIN (mg · L^{-1})	1*	7.45	6.45
	6**	7.60	7.65
Minimum Winter Hypolimnetic Oxygen Concentration WOMIN (mg · L^{-1})	1	7.18	6.93
	6	7.49	7.37
Number of Cottages		12	98
Number of User-days (yr^{-1})		5994	48958
Ice-free Period		7.62	10.83
Phosphorus Concentration YCPLK (mg · L^{-1})	1		
	6	7.62	10.83
Summer Average Chlorophyll *a* Concentration CHLOR (mg · L^{-1})	1	1.43	2.27
	6	1.43	2.27

* Baseline scenario using the Charlton (1979) AHOD equation
** Baseline scenario using the Cornett-Rigler (1979) AHOD equation with lake depth doubled

In summary, these results suggest that lakes with only partial turnover patterns are significantly more sensitive to development than lakes that are fully dimictic, i.e. experience complete mixing in spring and fall. The nutrient assimilation capacity is severely reduced in lakes with partial mixing, since dangerously low hypolimnetic oxygen conditions develop far sooner under these physical constraints than in lakes with complete mixing.

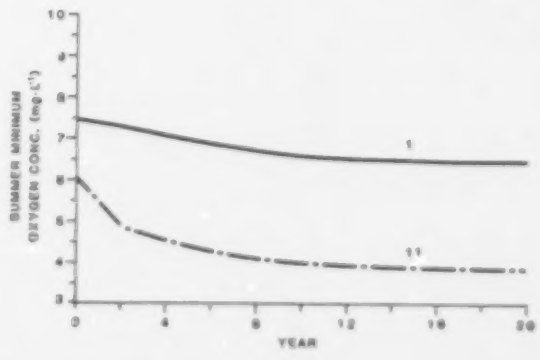


Figure B.6 Comparison of minimum summer hypolimnetic oxygen (SOMIN) curves for a lake with a complete (Run #1) and simulated partial (Run #11) spring water-mass mixing regime

B.3.5.2 WINTER

The minimum oxygen concentration[3] during the winter is calculated using the multiple regression equation of Welch et al (1976), which relies on Secchi depth, mean depth, maximum lake depth and lake flushing rate. Since there is no stratification during the winter, oxygen concentrations are assumed to be homogeneous throughout the water mass. As with the summer season estimate, the assumption is that a complete fall turnover takes place, rejuvenating any anoxic region of the hypolimnion. A 75% fall turnover can result in a severe winter oxygen depression (Figure B.7).

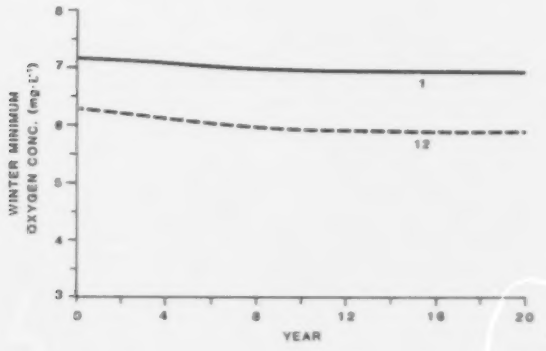


Figure B.7 Comparison of minimum winter hypolimnetic oxygen (WOMIN) curves for a lake with a complete (Run #1) and simulated partial (Run #12) fall water-mass mixing regime

B.3.5.3 IMPLICATIONS

When a partial spring and fall turnover was simulated for a lake with a moderate amount of development (as on the test lake), oxygen levels declined rapidly. Within two years they reached critically low concentrations (<3 $mg \cdot L^{-1}$) for trout and char, fish that cannot survive for long in water with oxygen levels less than 5 $mg \cdot L^{-1}$. Without adequate mixing, anoxic conditions can develop, resulting in "winter kills" once an ice cover has formed on the lake. Mathias and Barica (1980) showed that there is an oxygen concentration threshhold at 4.0 $mg \cdot L^{-1}$ for ice covered lakes, below which any mixing or agitation of the water mass only hastens the oxygen depletion process. This condition is aggravated in shallow lakes.

The oxygen algorithm used in the Water Quality Submodel is most sensitive to the spring and fall oxygen concentrations, which form the starting points for the summer and winter oxygen cycle. Developing the methodology for predicting the amount of turnover is essential for improving the model's ability to project minimum oxygen concentration.

[3] Both winter and summer oxygen equations produce estimates of daily oxygen depletion rates (AHOD) which are then converted to seasonal depletion rates by the following formula: Oxygen depletion in $mg \cdot L^{-1} \cdot season^{-1}$ = (AHOD/ZHYPO • 30/1000) • SEAL(2) where ZHYPO = mean thickness of the hypolimnion (m); AHOD is $mg \cdot m^{-2} \cdot day^{-1}$; SEAL (2) = summer season length in months, i.e. 5.5; 30 = average number of days/month; and 1000 = conversion to volumetric measure. For winter oxygen calculations SEAL (4), i.e. 4.5 months, is used and ZHYPO is replaced by mean depth of lake. The seasonal oxygen depletion rate is then subtracted from the oxygen value at the start of the season, i.e. at turnover, to yield the minimum oxygen level in that season.

B.4 FISHERIES

In the Fisheries Submodel, three elements control the year-to-year fluctuation in population size.

a) physical and chemical condition of the water body, e.g. depth, nutrient concentrations;
b) biological survival factors, i.e. natural growth, birth and death, and
c) fishing activity and fish harvest.

How sensitive is the Fisheries Submodel to changes in the key parameters associated with these three elements?

B.4.1 LAKE MORPHOMETRY AND TROUT PRODUCTION

The basis for the Fisheries Submodel is the morpho-edaphic index (MEI), a ratio of total dissolved solids to mean depth. In addition, since one of the variables in the fishing effort estimator is lake surface area, fisheries predictions are generally quite sensitive to changes in the physical measurements of a lake.

B.4.1.1 LAKE TROUT

With a doubling of the lake depth, carrying capacity and trout biomass are initially slightly lower (Figure B.8). The lake productivity is reduced because a smaller proportion of the lake volume is penetrated by light. The biomass at maximum use is similar for depths of 12.5m and 25m. However, an increase in lake surface area by 2.5 times dramatically changes the slope of the line. With an increase in lake surface area, the initial biomass is lower and the decline is considerably more gradual. This suggests that larger lakes have a greater production capacity and, therefore, the fishery in the larger lake will show a more gradual negative response to increased angling pressure than will the fishery in the smaller lake. Increasing simultaneously the depth and surface area depresses the line slightly but does not change its slope significantly.

B.4.1.2 SMALLMOUTH BASS

The relationships described for lake trout also hold true for the smallmouth bass.

B.4.2 NUTRIENT ENRICHMENT AND FISH PRODUCTION

B.4.2.1 LAKE TROUT

Because the total dissolved solids (TDS) are commonly 10^4 times that of the phosphorus concentration, fluctuations in phosphorus have little effect on the TDS (Ryder et al 1974). For this reason the MEI, which is derived from the TDS, is not responsive to nutrient enrichment generated from development. Based on research findings regarding fish productivity (Oglesby 1977b, Matuszek 1978, Prepas 1983) and data from 26 Fisheries Component study lakes, a regression equation was developed to relate the mean ice-free period P and the MEI. This equation provides a mechanism for raising the MEI as phosphorus levels increase due to nutrient contributions to the lake from lakeshore cottages. The adjusted MEI (XMEI), in turn, raises the fish yield estimate.

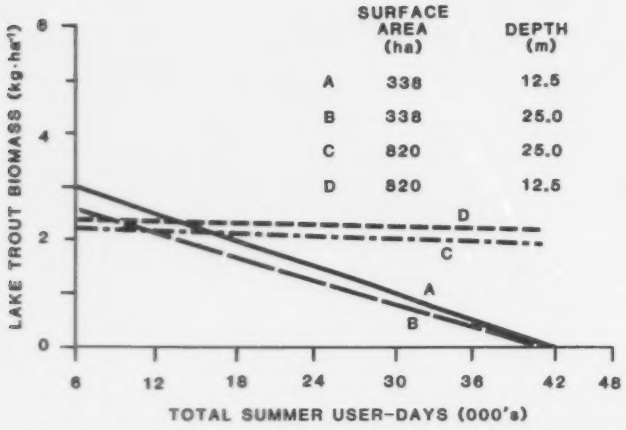


Figure B.8 Influence of changes in lake surface area, lake depth and user-days on lake trout biomass estimates

$$XMEI = 178595.6 * (YCPLK/1000)^{2.3552} \quad (B.2)$$
$$r^2 = 0.78$$
$$n = 26$$

where YCPLK = the mean ice-free period phosphorus concentration ($\mu g \cdot L^{-1}$).

By substituting Equation B.2 into Ryder's 1967 MSY formulation

$$MSY = 1.39 * (MEI)^{0.447} \quad (B.3)$$

then $$XMSY = 1.39 * (XMEI)^{0.447}. \quad (B.4)$$

In highly oligotrophic lakes, nutrient enrichment has a positive influence on lake trout production (represented by carrying capacity K in Figure B.9) by improving the food resources of the fish. However, the opposing actions of enrichment, plant growth-decay and oxygen depletion, can rapidly and severely limit the waterbody's lake trout production capacity by reducing the amount of suitable habitat (K-curve, Figure B.9). In the submodel, this balance is provided by a reduction in the lake trout carrying capacity in response to low oxygen levels.

The enrichment – lake trout production relationship is lake specific. A good knowledge of background enrichment, oxygen concentrations and the lake's water regime is essential for assessing the direction and amount of change resulting from nutrient enrichment of a lake.

B.4.2.2 SMALLMOUTH BASS

In contrast to the response of lake trout, smallmouth bass thrive in enriched waters and only with extreme nutrient additions would the smallmouth bass carrying capacity of the lake (K-curve) start to decline.

B.4.3 NATURAL GROWTH RATE

The relationship between natural fish growth rate and fish biomass (Schaefer 1957) can be shown algebraically:

$$B = K\frac{(1-qE)}{R} \quad (B.5)$$

where B = fish biomass ($kg \cdot ha^{-1}$);
K = carrying capacity ($kg \cdot ha^{-1}$);
q = fish catchability coefficient;
R = natural fish growth rate; and
E = fishing effort (angler-hours $\cdot ha^{-1}$).

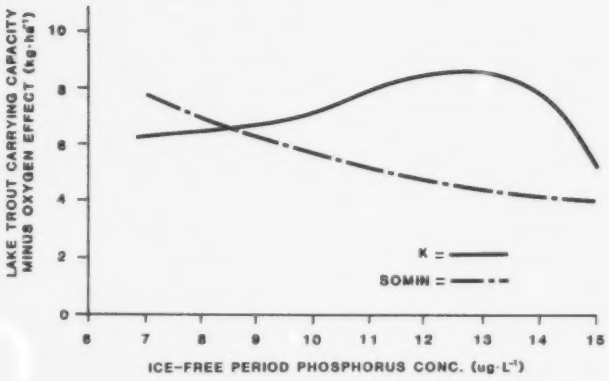


Figure B.9 Sensitivity of lake trout carrying capacity (K) to the drop in the minimum summer hypolimnetic oxygen concentration (SOMIN), as a function of increasing phosphorus (YCPLK)

In Equation B.5, the term in brackets represents the net growth proportion of K. At low natural growth rates (R), initial biomass is very high as a smaller proportion of the biomass has reached recruitable (fishable) size. In this case, many fish are not catchable. The biomass drops off rapidly in response to increasing user-days (Figure B.10). As the growth rate increases, the slope and intercept of the curves approach zero. This pattern occurs because the carrying capacity is inversely proportional to the intrinsic (natural) population growth rate R, that is, as R rises, K and B drop. Using this formulation, high initial fish biomass does not mean that stocks can tolerate intensive fishing. In fact, the opposite is true. With low fishing effort and a poor growth rate (R), initial biomass estimates are high because the stock is underfished (not at a fishable size) and a surplus biomass exists. As the effort rises, coupled with the same slow growth rate, the replacement of harvested fish rapidly loses ground to harvesting (Figure B.10, top curve). With a higher R, there is a higher initial catch and thus a lower initial biomass. However, the biomass declines more gradually due to the faster growth rate and replacement capacity of the population.

In summary, growth rates need to be carefully determined as they can cause markedly different biomass predictions.

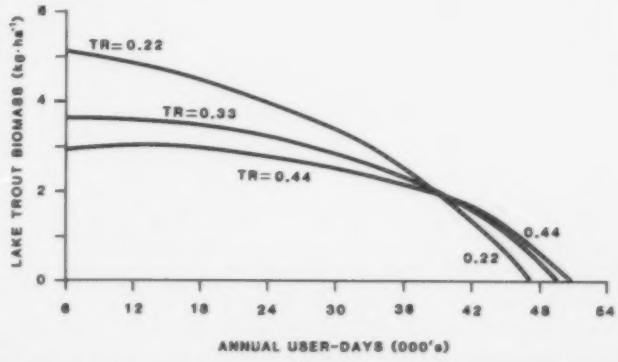


Figure B.10 Sensitivity of biomass predictions to changes in the intrinsic growth rate (TR) for lake trout

B.4.4 CATCHABILITY COEFFICIENT AND TROUT BIOMASS

The catchability coefficient (q) is the proportion of the fish population removed by one unit of fishing effort (one angler-hour). The value of this parameter is difficult to calculate as it varies from species to species, lake to lake, one age group to another and, also, as a function of the fish population density and the skill of the fisherman. The development of q for both lake trout and smallmouth bass for this version of the OLCSM is discussed in Chapter 6. In order to illustrate the model's sensitivity to changes in q values, q was varied from 0.005 to 0.10 and baseline conditions were used for all other input data (Figure B.11).

As q was increased, the biomass dropped off with increasing sharpness in response to a rising number of user-days. The indicators of fish biomass were extremely sensitive to changes in q. Therefore, accurate estimates of q are essential to the production of credible predictions of fish harvest and biomass.

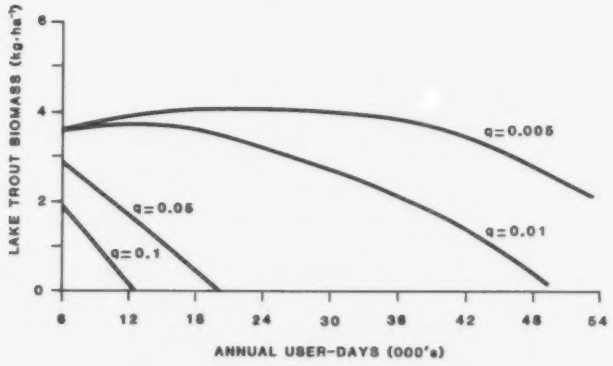


Figure B.11 Sensitivity of biomass estimates for lake trout to variations in the catchability coefficient (q)

B.4.5 FISHING EFFORT FROM COTTAGE-DAYS

Fishing effort is allocated to cottagers and non-cottagers by season. The process is accomplished in two steps: 1) calculate summer fishing effort, and 2) generate winter effort from summer effort through a mathematical relationship.

The submodel program contains two methods for estimating cottager fishing effort in summer. The first method uses the proportion of annual total cottage-days occurring during the summer fishing season, from projections made in the Land Use Submodel; the second method invokes an equation developed by the Fisheries Component researchers (McCombie 1983) which estimates effort from lake surface area and the number of cottages.

The former is discussed here as it is most appropriate to sensitivity testing and uses information supplied directly by the Land Use Submodel. Seasonal use figures are obtained by summing the monthly portions of annual cottage use over a defined number of months. Using this process, a summer use figure (FUSES) is derived which, in turn, is multiplied by four parameters describing fishing habits. The equation is:

$$EFFS = (FUSES * PFISH * ANGLER * HOURS * PTIME) / AREAL \quad (B.6)$$

		Default Values
where EFFS =	cottager angler-hours in summer per ha of lake;	
FUSES =	cottage-days in summer fishing season;	
PFISH =	proportion of cottages with occupants who fished in summer (Downing, pers. comm.);	0.50
ANGLER =	number of anglers per fishing trip (MNR);	2.00
HOURS =	number of hours per fishing trip (MNR);	2.00
PTIME =	proportion of cottage-days, as defined by PFISH * FUSES, when fishing actually takes place; and	0.33
AREAL =	lake surface area in ha.	

Changing the number of cottage-days allocated to the fishing season has a dramatic effect on the effort estimate. For example, by raising the summer's proportion of annual use by 10%, the variable FUSES rises in direct proportion. The four default values for the fishing habit parameters (PFISH, ANGLER, HOURS and PTIME), when multiplied together, equal 0.66; therefore, summer fishing effort is 0.66 of the summer cottage-days. Estimates of fishing effort would be significantly changed if one or a combination of these parameters were altered.

These four parameters (Equation B.6) are lake-specific but failing anything better, the default values can be used as long as an "average" interpretation is applied.

B.4.6 PARTITIONING FISHING EFFORT AND MSY

In order to make species-specific biomass and harvest estimates, surplus production (MSY) and total fishing effort are divided among lake trout, smallmouth bass and other species. Effort is allocated according to creel census results and is lake specific. Clearly, any changes in these allocations would be directly reflected in the catch estimates.

Maximum sustained yield for the overall fish community is allocated in two stages: first, in terms of the true proportions (according to biomass) and, second, in terms of safe (optimum) levels which may be harvested from the lake indefinitely. These safe levels are designated at 0.25 MSY_c for lake trout and 0.50 MSY_c for smallmouth bass (McCombie 1983, MNR 1982). Any modification in these values would directly alter the MSY and the growth-harvest relationship for these fish species. Great care is needed in determining and/or modifying these parameters.

If no empirical data are available, field experts familiar with the lake should be asked to provide their best estimates.

A summary of the fisheries-related simulation runs and the resulting predictions is presented in Table B.9.

Table B.9 Sensitivity of fish biomass to changes in lake morphometry, water quality, fishing and fish population dynamics

Lake Simulation Run	Scenario tested	Simulation time	User-days	Lake surface area (ha)	Lake mean depth (m)	Annual growth rate	Lake Trout catchability coefficient (q)	MSY			Summer Lakewide Fishing effort for lake trout (angler-hrs · ha^{-1})	Nutrient P conc. (μg · L^{-1})	Lake Trout		
								All fish	Lake Trout	Prop'n for Lake Trout			Carrying capacity	Biomass (kg · ha^{-1})	Catch
								(kg · ha^{-1} · yr^{-1})							
1	Baseline	Start	5995	338	12.5	0.33	0.01	2.16	0.54	0.25	2.36	7.6	6.5	3.6	0.18
		Yr. 20	48958					2.64	0.66		23.20	10.8	8.0	0.15	0.09
6	Double lake depth	Start	5995	338	25.0	0.33	0.01	1.84	0.46	0.25	2.36	7.6	5.5	3.0	0.15
		Yr. 20	48958					2.64	0.66		23.20	10.8	8.0	0.15	0.09
4	Double lake depth and surface area	Start	5995	820	25.0	0.33	0.01	1.56	0.39	0.25	0.91	6.3	4.8	2.72	0.05
		Yr. 20	48958					1.88	0.47		8.80	7.8	5.7	2.41	0.50
							Changes in Fish and Fishing Parameters								
3	Large lake surface area and increased annual growth rate of fish	Start	5995	820	12.5	0.44	0.01	2.12	0.53	0.25	0.91	6.1	4.9	2.9	0.05
		Yr. 20	48958					2.12	0.53		8.80	7.7	4.9	2.7	0.54
5	Same as 3 but growth rate increased further	Start	5995	820	12.5	0.55	0.01	2.16	0.54	0.25	0.91	6.3	3.9	2.4	0.04
		Yr. 20	48958					2.16	0.54		8.80	7.9	3.9	2.5	0.50
7	Same as 4 but more phosphorus available and MSY proportion for trout is up	Start	5995	820	25.0	0.33	0.01	2.40	0.84	0.35	2.36	9.9	10.2	5.7	0.28
		Yr. 20	48958					3.36	1.20		23.20	13.9	14.6	0.27	0.18
8	Same as 1 but reduced P and available prop of trout MSY is up	Start	5995	338	12.5	0.33	0.01	2.13	0.96	0.45	2.36	6.1	11.7	6.48	0.32
		Yr. 20	48958					2.13	0.96		23.20	8.8	11.7	0.16	0.10
13	Reduced catchability for trout	Start	5995	338	12.5	0.33	0.005	2.12	0.53	0.25	2.36	7.6	6.5	3.64	0.14
		Yr. 20	48958					2.64	0.66		23.20	10.8	8.0	0.60	0.27
11	Slightly reduced initial P but increased trout catchability (Partial spring turnover)	Start	5995	338	12.5	0.33	0.05	2.12	0.53	0.25	2.36	5.3	6.5	3.29	0.49
		Yr. 20	48958					2.64	0.66		23.20	10.8	5.0	0.	0.
12	Increased trout catchability	Start	5995	338	12.5	0.33	0.10	2.12	0.53	0.25	2.36	7.6	6.5	2.91	0.87
		Yr. 20	48958					2.64	0.66		23.20	10.8	8.0	0.	0.

B.5 WILDLIFE HABITAT

The Wildlife Submodel contains equations and relationships which provide estimates of the response of birds, small mammals, furbearers, ungulates and herptiles to changes in their natural habitat.

As this submodel deals with over 30 animal species, each with varying sensitivities to habitat removal, a detailed analysis of each species is beyond the scope of this report. However, some generalities are appropriate.

B.5.1 HABITAT DISTURBANCE

Wildlife researchers identified a strong relationship between the lot area (lot width (m) * 50 m) and the proportion of the area disturbed in the ground, shrub and tree vegetation layers. Although the actual area disturbed was independent of lot size, the proportion of the lot disturbed decreased as the lot size increased (Figure B.12).

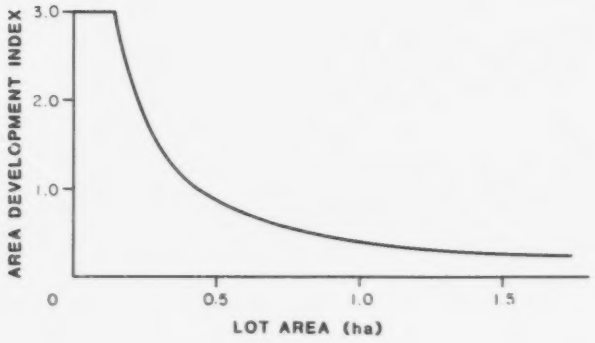
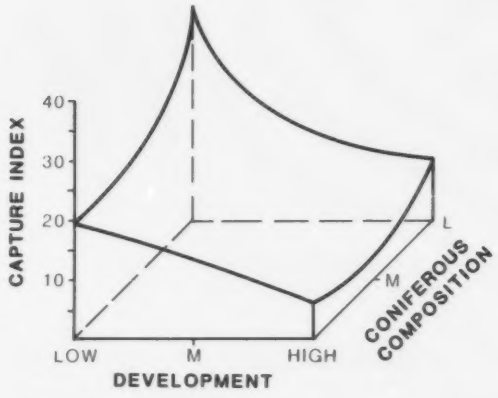


Figure B.12 Area Development Index and its relationship to cottage lot size

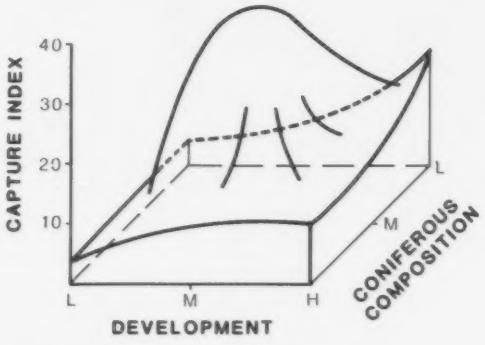
B.5.2 SMALL MAMMALS

The seven small mammals studied vary in their sensitivity to development. An overriding sensitivity criterion for all species is their response to the removal of preferred habitat. The sensitivity of these animals to change in their habitat is shown in the complex, sensitivity response, surface diagrams (Figure B.13). For example, the graph for the deer mouse suggests that this species is sensitive to development, as indicated by the steep slope of the graph along the development axis. Moreover, this species' sensitivity to a shift from deciduous to coniferous tree cover at low levels of development is illustrated by the slope of the line from the peak of the graph and along the axis of coniferous composition. Sensitivity to a change in forest cover type is pronounced for the red squirrel. Any removal of coniferous tree cover, as by the selective cutting of coniferous trees, severely reduces this species' usable habitat.

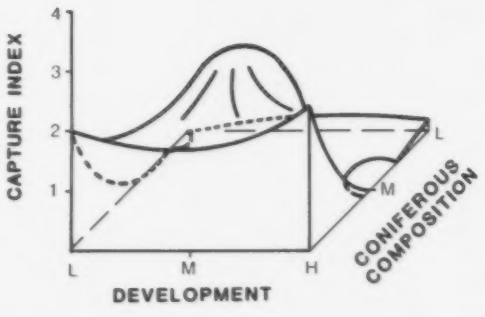
Four of the seven species studied appear to prefer deciduous tree cover and the associated understorey plant community (Racey and Euler 1982). Clearly small mammals are sensitive to changes in the forest cover type.



A. DEER MOUSE



B. EASTERN CHIPMUNK



C. RED SQUIRREL

Figure B.13 Response of three small mammal species to changes in the level of development and the forest cover composition (from Euler 1983)

B.5.3 MINK

Mink prefer coniferous habitat and are seriously affected by disturbance from lakeshore development (Figure B.14). The relationship of the Area Development Index (amount of disturbed habitat) to the mink activity index (Figure B.15) suggests that mink populations may decline to 20% of their activity level (population size) with a 0.5 unit increase in the Area Development Index.

As with the small mammals, careful identification of the type of tree cover along the lakeshore is essential for providing sound predictions of the mink's response to development.

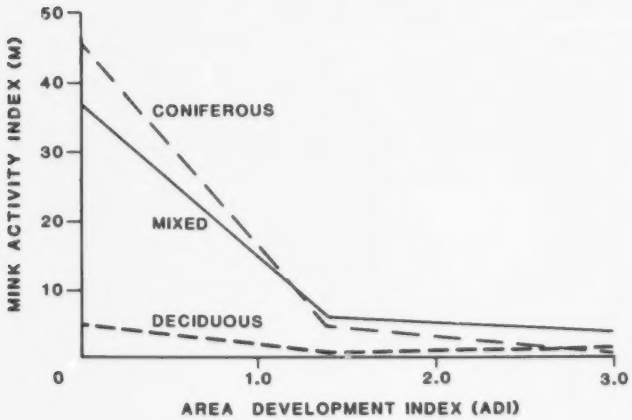


Figure B.14 Mink activity as a function of the Area Development Index, for three forest cover types

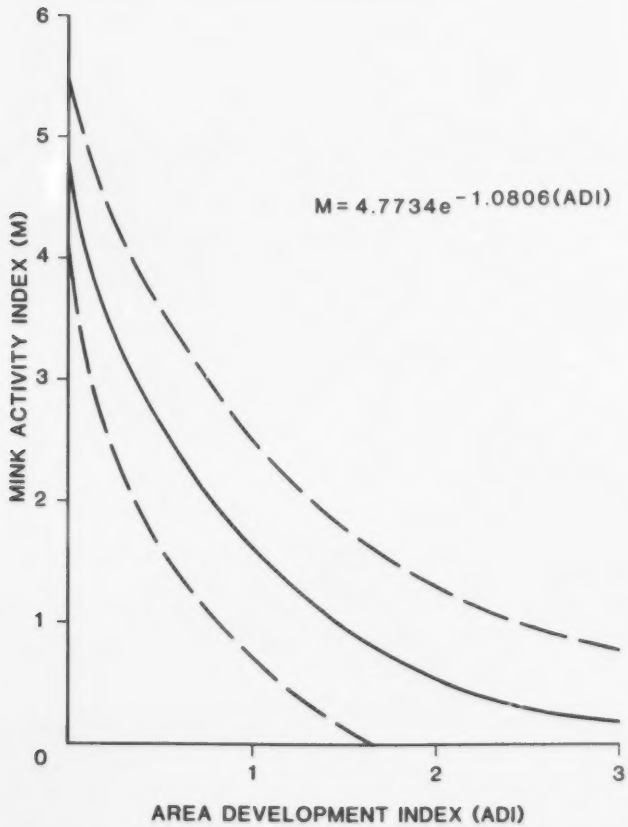


Figure B.15 Relationship of the Mink Activity Index (M) to the Area Development Index (ADI)

B.5.4 SONGBIRDS

Songbirds respond rapidly to a change in the type of tree cover. Species associated with areas of low tree volume, low tree density and little understorey can tolerate habitat disruption, while species associated with dense, closely-spaced stands are intolerant of habitat alteration. The 19 species examined were most sensitive to canopy volume, tree density and amount of understorey. Here, as with the small mammals, it is the change in type of forest cover which determines the degree of response by the songbirds.

Wildlife biologists have established critical threshhold levels of disturbance for each of the songbird species. These are programmed into the submodel and, at each iteration, they are compared with the predicted disturbance to determine the amount of suitable songbird habitat.

B.6 NATURAL VARIATION

The model contains a built-in feature which permits the user to add natural variation to the input parameters (Section 5.3). Presently this is done only in the Water Quality Submodel. However, as output from this submodel is used in the Fisheries Submodel, the variation is transferred to the fisheries indicators. The sensitivity of the water quality and fisheries indicators to natural variation is examined here.

Mean ice-free period phosphorus concentration changes markedly with natural variation (Figure B.16 a & b). After a ten-year simulation on one test lake, the naturally-varied P value was 0.7 $\mu g \cdot L^{-1}$ less than the estimate made without natural variation. A further example (Figure B.16 c & d) shows the total annual phosphorus delivered to the lake (YPLOAD) and the total P flushed downstream (SDOWNP). The phosphorus retained in the lake (shaded area on graph) varies significantly from the run without random variation. There is a certain amount of "compensation", as during wet years the greater input of nutrients from the watershed is countered by increased downstream flushing; the opposite is true for dry years. However, in this example there seems to be greater flushing than input, resulting in a reduced phosphorus load in the lake after 10 years (Figure B.16 d).

Other water quality indicators are affected when natural variation is implemented in the model. Oxygen, however, responds inversely to phosphorus, i.e. as P supplies drop, oxygen concentrations rise.

With natural variation applied (Figure B.16 f) in the Fisheries Submodel, trout biomass levels are as much as 0.5 $kg \cdot ha^{-1}$ below the standard run (Figure B.16 e), resulting in lower surplus fish production.

In conclusion, the application of natural variation suggests that resulting predictions will fluctuate by as much as 30% from the results of non-naturally varied runs. In view of this high level of sensitivity, it is recommended that simulations be run with the natural variation option.

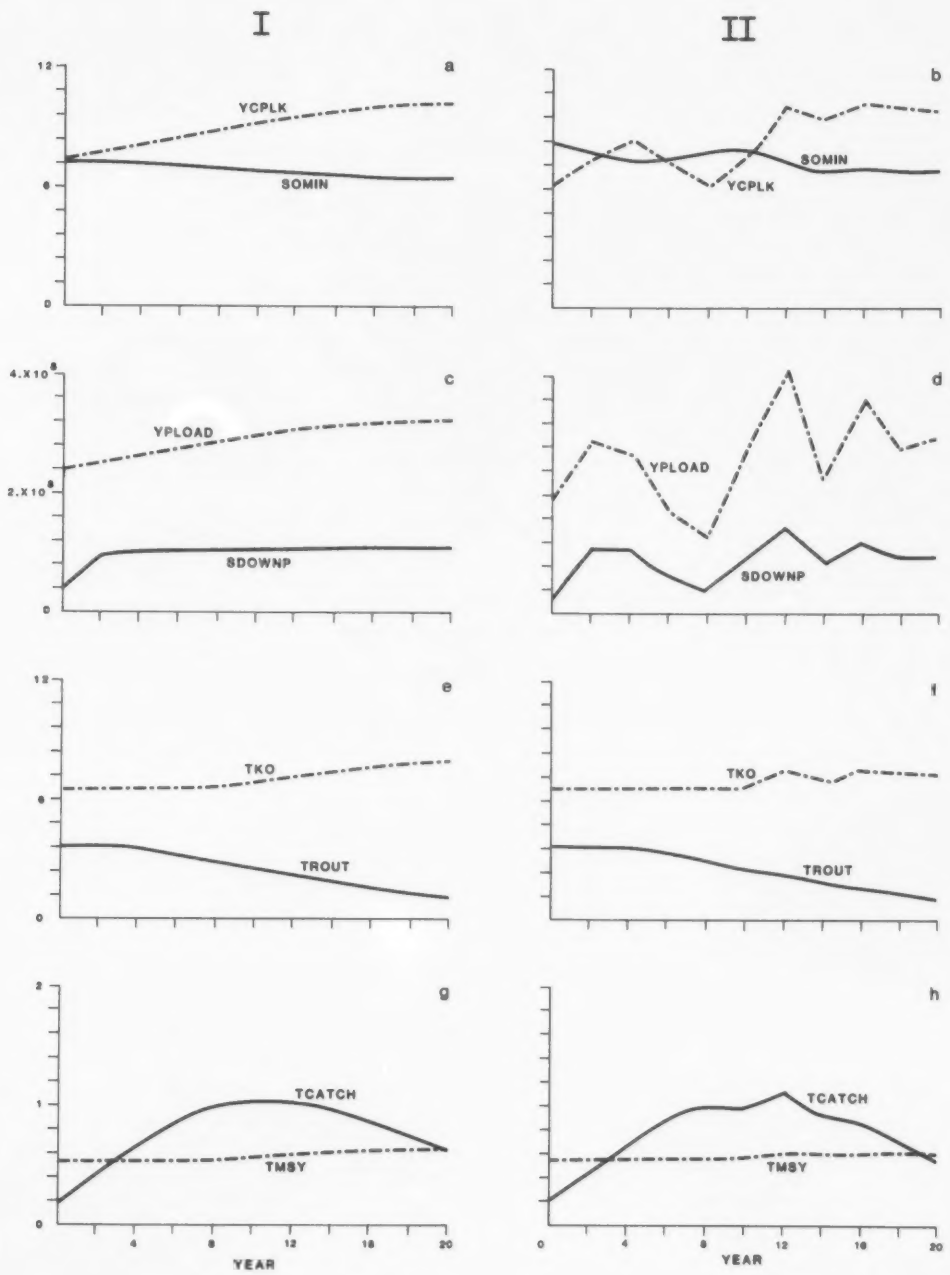


Figure B.16 Comparison of predictions without (I) and with (II) natural variation for mean ice-free period phosphorus concentration (YCPLK) and summer hypolimnetic oxygen (SOMIN); total phosphorus supply (YPLOAD) and total downstream losses of phosphorus (SDOWNP); lake trout carrying capacity (TKO) and biomass (TROUT); and lake trout maximum sustained yield (TMSY) and catch (TCATCH)

APPENDIX C. AN EXAMPLE OF MODEL APPLICATION

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C.2 OVERVIEW OF SIMULATIONS

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Figure C.1 An example of model application

AN EXAMPLE OF MODEL APPLICATION

The method of applying the OLCSM and interpreting the model output is demonstrated in the following example of a proposed plan of subdivision on hypothetical Lake Z in the Muskoka-Haliburton area of Ontario.

Lake Z is an oligotrophic lake with a lake surface of 350 ha. The lake supports a lake trout fishery and other sport fish species, including smallmouth bass, lake whitefish and yellow perch. Winter fishing is permitted on the lake. A public boat launching ramp provides boat access for non-cottagers.

Existing lakeshore development consists of 65 cottages and 20 vacant lots. The proposed plan of subdivision includes 13 lots, arranged in a single tier along the lakeshore. If cottages are constructed on all vacant and proposed lots, during the course of the simulation, there will be a 51% increase in the number of cottages. Roads leading to the existing cottages, vacant lots and proposed lots are hard-surfaced and open in winter.

In order to predict cottage-days and user-days, it is essential to know 1) the type of existing access to the cottages and lots; 2) whether there is an official plan for the municipality or region and, if there is, the policies regarding permanent and seasonal use; 3) whether such policies have been implemented through zoning regulations; and 4) whether there are plans for roads that would change the existing type of access to the subdivision, the distance to the nearest high order urban service centre or the distance on poor roads.

In the case of Lake Z, there is neither an official plan nor a zoning by-law containing restrictions on permanent use for the area, so it is assumed that some cottages may be used all year. Further, there are no plans for new roads or improvements that would change the type of access to existing or proposed lots.

C.1 OLCSM PREDICTIONS

During the period of the simulation, cottages are assumed to be constructed on all remaining vacant lots, at a rate of 20% annually. The same rate is applied to the proposed subdivision, which is started in year three. The length of each simulation, in this case, is 20 years — a long-term planning horizon.

The conditions for each scenario appear in Table C.1. The model is run with the existing development (Scenario 1), followed by the addition of a proposed subdivision (Scenario 2). Scenarios 3 through 6 simulate the impact of both existing and proposed development when selected mitigative measures are applied.

Table C.1 Specified conditions for Lake Z simulations

SCENARIO	1	2	3	4	5	6
Variables	Existing Development	Existing & Proposed Development	Scenario 2 Plus No Winter Fishing and Holding Tanks	Scenario 2 Plus Summar and Winter Fishing Restrictions and Lot Relocation	Scenario 2 Plus Redistribution of Fishing Pressure, No Winter Fishing and Increased Lot Width	Scenario 2 Plus Road Closed in Winter
Existing number of occupied lots	65	65	65	65	65	65
Existing number of vacant lots	20	20	20	20	20	20
Proposed number of lots	0	13	13	13	13	13
Total number of lots	85	98	98	98	98	98
Sewage disposal system	septic	septic	holding tanks on proposed lots	septic	septic	septic
Summer fishing season	May-Sept.	May-Sept.	May-Sept.	July-Sept.	May-Sept.	May-Sept.
Winter fishing	yes	yes	no	no	no	yes
Proportion of angling effort for lake trout	0.60	0.60	0.60	0.60	0.30	0.60
Proposed subdivision design	NA	unchanged	unchanged	lot relocation	double lot width	unchanged
Winter roads	yes	yes	yes	yes	yes	no

SCENARIO 1: EXISTING DEVELOPMENT

The existing development consists of 65 cottages and 20 vacant lots on which new cottages will be constructed during the simulation.

The model projections indicate that the water quality indicators (Figure C.1 C) in year 1 of the simulation (present conditions) are marginally within the Ministry of the Environment's water quality level #1. This level represents the range of phosphorus (1-10 $\mu g \cdot L^{-1}$) and chlorophyll *a* (0-2 $\mu g \cdot L^{-1}$) concentrations in unenriched waters, which provide optimal habitat conditions for cold water fish species, such as lake trout.

The lake nutrient concentration increases during the simulation as a result of the additional user-days associated with cottages constructed on existing lakeshore lots. After the 20-year simulation (Table C.1, Scenario 1), the water quality indicators reflect levels of nutrient enrichment found in moderately enriched waters, i.e. water quality level #2. This level is acceptable for body contact recreation, such as swimming and water-skiing, as well as boating and fishing. However, level #2 is not compatible with the preservation of the cold water fisheries.

Nutrient enrichment has a potentially negative effect on lake trout, due to oxygen depletion. The minimum oxygen concentrations in the simulation (6.6 $mg \cdot L^{-1}$) approach the 5-6 $mg \cdot L^{-1}$ range, which represents the minimum levels to which lake trout can be exposed for extended periods without adverse effects (Figure C.1 C). Since the summer minimum oxygen prediction reflects the average value in the hypolimnion, a value close to this range may result in dangerously low levels at the sediment surface. This suggests possible stress on the lake trout, through reduction in the amount of suitable habitat.

Overfishing for lake trout is indicated from the estimate of lake trout catch at the start of the simulation. In year one, it is double the maximum sustained yield, or the surplus production, for that species (Figure C.1 D). The nutrient additions which improve the fish food base are not great enough to offset the effects of the existing high level of fishing activity on the lake. The result is a steep decline in the lake trout stock, which causes virtual extinction of the population.

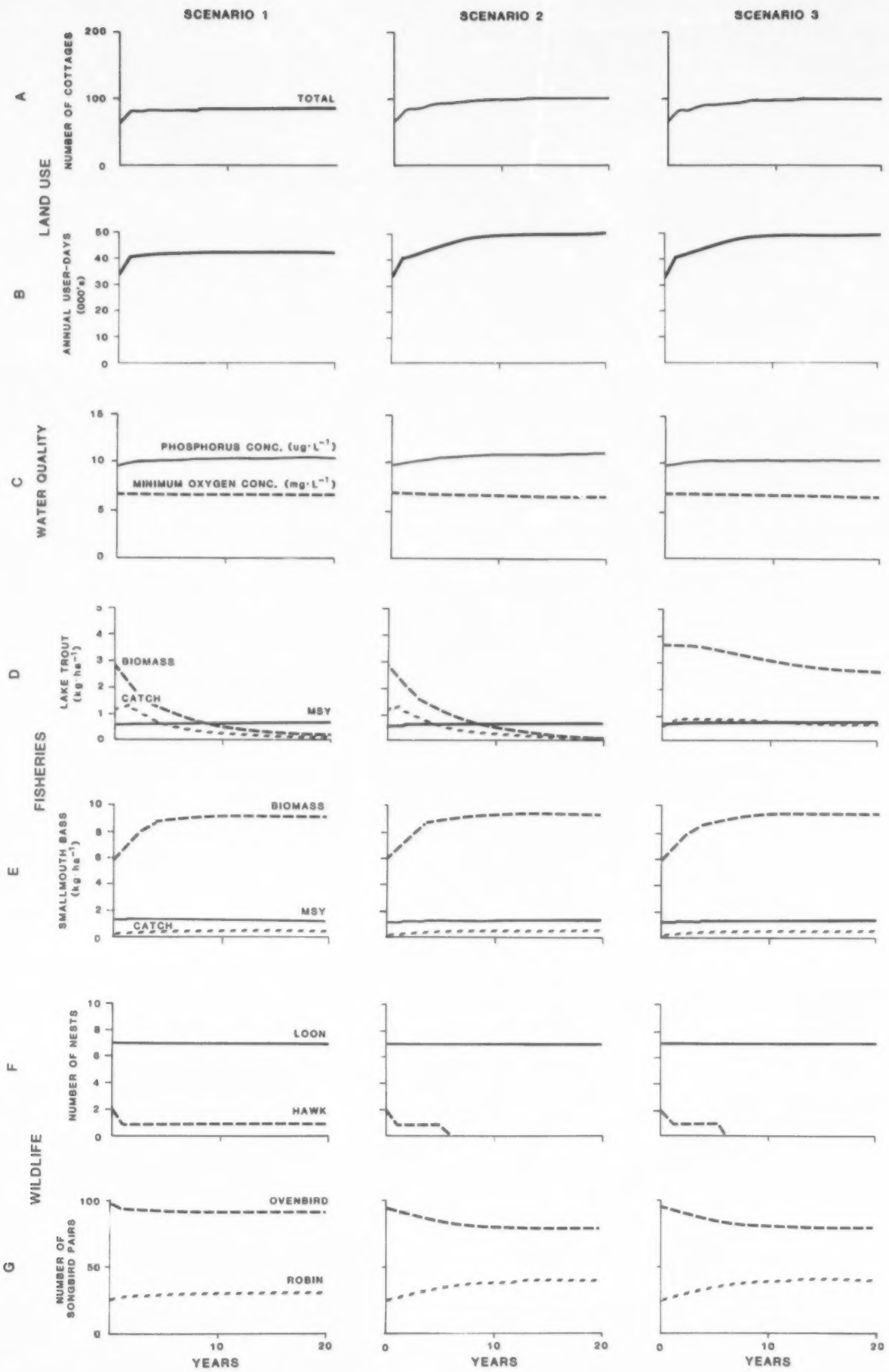
The smallmouth bass catch, on the other hand, remains well below the maximum sustained yield (Figure C.1 E). The smallmouth bass population actually increases for the first five years, then stabilizes at a higher biomass level. This species is less sensitive than lake trout to angling pressure and reduced oxygen concentration. In addition, there is some evidence that rock cribs used as dock foundations, which are associated with cottage development, provide shelter for young bass.

The seven potential loon nesting sites identified on the lake are located on small islands more than 50 m from the shoreline, so it is assumed that these nesting sites are undisturbed by the additional cottages (Figure C.1 F). However, when new cottages are built on existing vacant lots, one of the two potential broad-winged hawk nesting sites, being close to a cottage, will no longer be suitable for that purpose. The preservation of at least two suitable nesting sites for each species (broad-winged hawk and common loon) is recommended by the Ministry of Natural Resources wildlife scientists, in order to ensure the probability of at least one nesting pair of each species on a lake.

The American robin is an example of a songbird species that is tolerant of development. The number of breeding pairs of robins around the lake increases (Figure C.1 G) as cottages are constructed on existing vacant lots, creating more open habitat. On the other hand, songbird species such as the ovenbird cannot tolerate the vegetation changes associated with development, as these species typically inhabit undisturbed forests.

Examination of other lakeshore wildlife indicates low levels of disturbance. For example, more than 70% of the original songbird habitat and mink activity are retained at the end of the simulation.

It is apparent from this simulation that the existing development is exerting stress on the fishery and the lake water quality.


SCENARIO 1
SCENARIO 2
SCENARIO 3
A
LAND USE
NUMBER OF COTTAGES
200
100
0
TOTAL
B
ANNUAL USER-DAYS (000's)
50
40
30
20
10
0
C
WATER QUALITY
PHOSPHORUS CONC. (ug·L⁻¹)
MINIMUM OXYGEN CONC. (mg·L⁻¹)
15
10
5
0
D
FISHERIES
LAKE TROUT (kg·ha⁻¹)
BIOMASS
CATCH
MSY
E
SMALLMOUTH BASS (kg·ha⁻¹)
BIOMASS
MSY
CATCH
F
WILDLIFE
NUMBER OF NESTS
LOON
HAWK
G
NUMBER OF SONGBIRD PAIRS
OVENBIRD
ROBIN
0
10
20
YEARS

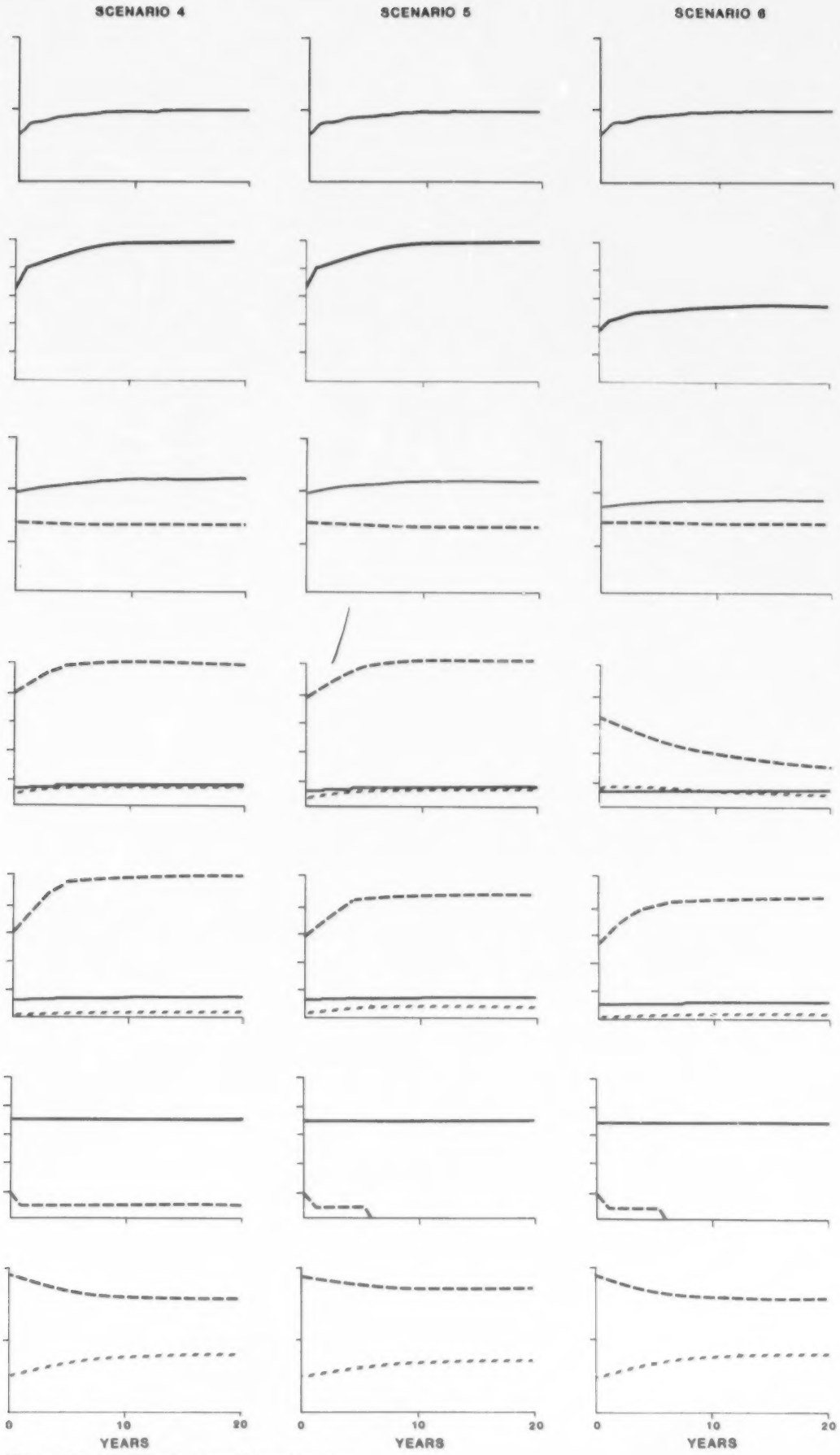


Figure C.1 An example of model application

SCENARIO 2: EXISTING AND PROPOSED DEVELOPMENT

The addition of 13 proposed lots to the existing development increases the total number of lakeshore lots to 98 (Table C.1, Scenario 2). When cottages with septic tanks are constructed on the 13 lots, lake enrichment is increased by a small amount. The 13% increase in the number of annual user-days, however, places the lake marginally within the moderately enriched category of lakes (water quality level #2).

The lake trout population declines slightly faster than with the existing development alone (Scenario 1), due to additional lake trout angling pressure from the proposed cottages. The new anglers increase the high level of fishing activity associated with the existing development.

Although the smallmouth bass angling effort increases, this pressure is offset by additional nutrients in the water, which increase the fish food base. The result is a net increase in the smallmouth bass biomass in the lake.

The number of suitable loon nesting sites is the same as in Scenario 1. However, because of the proximity of the hawk nesting site to the proposed cottages, the one remaining potential nesting site is lost.

As in Scenario 1, the number of robins increases but the addition of the proposed cottages causes a greater reduction in the number of ovenbirds, due to vegetation removal on the cottage lots.

Other wildlife species that are intolerant of development, such as mink, experience slightly more disturbance under Scenario 2, although the wildlife indices remain substantially above the levels designated by wildlife scientists as a minimum for preservation of these species around the lake.

The environmental indicators suggest that management strategies need to be considered for both the existing and proposed development. In order to mitigate the predicted environmental stresses in Scenarios 1 and 2, four additional scenarios were simulated (Table C.1, Scenarios 3 – 6), each involving the introduction of selected management strategies.

SCENARIO 3: EXISTING AND PROPOSED DEVELOPMENT (98 COTTAGES)

- **Holding tanks in proposed subdivision (13 lots)**
- **Winter fishing restrictions**

Holding tanks provide 100% removal of domestic sewage from the cottage site by disposal of the effluent in an acceptable manner, usually in a sewage treatment plant. The condition for subdivision approval specifying holding tanks prevents any further enrichment of the lake from human sources.

With the closing of the winter fishery, the lake trout catch at the start of the simulation is below the maximum sustained yield for the species (Figure C.1 D). Following year one, the lake trout summer harvest rises to exceed the maximum sustained yield, due to the increased number of cottages and user-days. This results in a steady lake trout biomass level for the first four years and a gradual decline in the biomass thereafter. Although the decline in the lake trout population is not desirable, over the long run the results may not be catastrophic. There is time for further scrutiny of the situation and re-evaluation of control measures.

The smallmouth bass population is unaffected by these restrictions since smallmouth bass are not a part of the winter harvest. They seek the warmest water at the bottom of the lake in winter and are relatively inactive.

SCENARIO 4: EXISTING AND PROPOSED DEVELOPMENT (98 COTTAGES)

- **Summer and winter fishing season restrictions**
- **Lot relocation in proposed subdivision**

Reduction in the length of the summer fishing season from May through September to July and August, plus the closure of the winter fishery, dramatically reduces the overharvesting of lake trout. The trout harvest remains below the maximum sustained yield throughout the 20-year simulation. The lake trout biomass increases during the first eight years and then stabilizes. The increase in lake trout can be attributed primarily to underfishing, that is, the incomplete harvest of the surplus production, which causes a rise in the total lake trout stock.

Due to the shorter summer fishing season, fishing pressure on the smallmouth bass is reduced. Because fewer bass are removed from the lake, the population rises to higher levels than in Scenario 2.

In year one of the simulation, one of the two potential hawk nesting sites is unsuitable, due to the construction of cottages on existing vacant lots. The potential of the other nest site is also eliminated by its proximity to cottages in the proposed subdivision (Scenario 2). To retain the hawk nesting potential, relocation of the proposed lots could be considered as a condition of subdivision approval. By developing at another location, the nesting site remains a safe distance from the source of disturbance. The number of lots in the proposed subdivision, in this case, is not reduced.

SCENARIO 5: EXISTING AND PROPOSED DEVELOPMENT (98 COTTAGES)

- **Redistribution of fishing pressure**
- **Winter fishing restrictions**
- **Larger lot sizes in proposed subdivision**

On many lakes in the Muskoka-Haliburton area, anglers are over-harvesting the cold water fish species, especially lake trout, and under-harvesting the warm water species. As stated in the MNR Minden District Land Use Strategy (Draft), a redistribution of fishing pressure from trout to non-trout species is necessary to meet the sport fish target set by the District (Ontario Ministry of Natural Resources 1982a). In some cases, lakes could sustain additional fishing pressure, if it were redirected to underutilized species.

In Scenario 5, the conditions of the simulation include a redistribution of angling effort from 60%:35% to 30%:65% (lake trout:smallmouth bass), thereby reducing the effort for lake trout by half and nearly doubling the effort for bass. Five percent of the total fishing effort is allocated to other species. In this case, when combined with restrictions on the winter fishing season, the lake trout catch remains within the estimated surplus yield for that species. Although the total number of angling hours is the same as in Scenario 3, the lake trout biomass no longer indicates a declining population. Where there is less severe overfishing, the redistribution of angler effort alone may stabilize the lake trout population. This strategy could be implemented by introducing fish quotas or undertaking an educational program to encourage voluntary restraint.

Lot width affects the amount of vegetation removed for cottages and, in turn, the impact on wildlife species that cannot tolerate changes in their habitat. By doubling the width of the proposed 30-m lots, more ovenbirds are retained on the lakeshore. The decline in breeding pairs of this species is less pronounced than with smaller lot sizes (Scenario 2). In contrast, species such as robins, that find suitable habitat in or near cottage clearings, do not increase as much under these conditions of reduced cottage density.

SCENARIO 6: EXISTING AND PROPOSED DEVELOPMENT (98 COTTAGES)

□ **Roads closed in winter**

This scenario is simulated to illustrate the implications of cottage accessibility with respect to cottage use. It is assumed that roads are closed in winter. Therefore, although a car can be used for summer transportation to the cottage, some other travel mode will be necessary to complete the trip to the cottage in winter.

Where roads are closed in winter, the amount of cottage use is considerably lower and non-cottager use of the lake in winter is reduced. In this case, 44% fewer user-days result in less nutrient enrichment of the lake and less fishing activity than in Scenario 2.

Even though the number of cottages is the same as in Scenario 2, the closed roads in winter virtually rule out the presence of permanent residents. Because permanent residents occupy their lakeshore cottages 365 days per year (compared with the average cottage use of 116 days per year), a high proportion of this group on a lake increases the total number of annual cottage-days.

The lake trout population declines gradually, due to overfishing, during the first eight years of the simulation. However, the impact may not be catastrophic. More stringent fishing restrictions or, perhaps, redistribution of angling effort might correct this situation.

C.2 OVERVIEW OF SIMULATIONS

The example demonstrates the method of predicting, interpreting and mitigating the impact of cottage development on a hypothetical lake. Other examples could be used to demonstrate that the same number of cottages may have quite a different impact on another lake with different lake and watershed characteristics. In addition, if cottages are built on an upstream lake, they may increase the phosphorus concentration in the lake and in the outflow streams, thus possibly affecting the cottage capacity of the downstream lake.

The effects of variations in such factors as number and location of cottages, type of cottage access, timing of construction, lake and watershed characteristics, type of wildlife habitat and selection of management strategies can all be simulated by applying the OLCSM. The resulting predictions of probable impact can assist planners in guiding development in ways that will avoid damage to the inland lake environment.